HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME II. HYDRO - HYDROLOGY

for:

Office of Technology Applications
Federal Highway Administration
Washington, DC

March 1999

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INTRODUCTION

This document introduces the computer program HYDRO. HYDRO is a hydrology analysis program developed for the Pooled Fund Project (PFP) and was written in FORTRAN. It is based on the Federal Highway Administration (FHWA) Highway Engineering Circular 19, HYDROLOGY (HEC-19), and as such, is an effort to combine existing approaches for rainfall and runoff analyses into one system.[(1)] HYDRO generates point estimates for a single design event. It is not a continuous simulation model. HYDRO uses the probabilistic distribution of natural events such as rainfall or stream flow, as a controlling variable. HYDRO should be considered as a computer based subset of HEC-19, with some areas of HEC-12 also included.[(2)] This documentation explains the concepts and theories used within HYDRO, although the user should refer to HEC-19 and other listed references for detailed explanations.

The documentation is divided into three sections: system operation, technical operation, and user application. The first section, system operation, provides insight into the capabilities and hydrological aspects covered in the program. The technical operation section provides data on how the system operation is achieved. Specifically, it provides the user with all equations and methodologies used by HYDRO when performing a hydrologic analysis. The last section demonstrates how to apply the program, particularly as it pertains to the HYDRAIN microcomputer package.

HYDRO is a tool that allows the highway drainage engineer to quickly make analyses of hydrologic problems. It is designed to be one of several programs within HYDRAIN, and therefore its output can be used by other programs as input. HYDRO can also be used as a stand-alone system. The program was written using structured programming techniques that allow system modularity and open architecture for expandability.

SYSTEM OVERVIEW

HYDRO capabilities are divided into three major hydrological scenarios: rainfall analysis, Intensity-Duration-Frequency (IDF) curve generation, and flow (runoff or stream flow) analysis. Rainfall analysis allows the user to investigate what will be categorized as steady-state (rainfall intensity) and dynamic (hyetograph) rainfall conditions. Both the rainfall analysis and IDF curve generation are a function of frequency, geographic location, and duration of the storm event. The third scenario, flow, permits the user to investigate several methods for determining peak flow. This peak flow can be the result of either runoff or gaged stream flow. As with the rainfall scenario, both steady-state (peak flow) and dynamic (hydrograph) flow conditions can be considered. Figure 1 shows the basic types of analysis available through HYDRO.

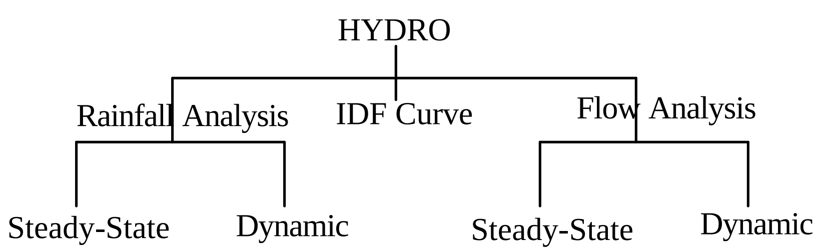


Figure 1. HYDRO flow chart.

RAINFALL AND IDF CURVE GENERATION

HYDRO can internally calculate rainfall intensities for any site in the continental United States. This rainfall intensity is a single peak rainfall. HYDRO can be used to create a hyetograph (a plot of rainfall intensity versus time). A site-specific IDF curve can also be estimated.

Rainfall Data Bases

Rainfall intensities are generated from values provided in either the default, Pooled Fund data base (RAIN.PFP) or a State-supplied data base. The option to access a State-supplied data base was added to HYDRO at the request of the California Department of Transportation (CALTRANS). This option addresses the problem experienced by users in California and other western States: the Pooled Fund data base is too coarse for regions where the climate varies greatly over short distances. It would not be wise to use the Pooled Fund data base when the site is within mountain ranges or similar topographic features.

The default data base consists of the 1- and 24-h rain durations for 2- and 100-yr return periods for a total of 5597 latitude/longitude coordinate pairs. The data base was developed from three sources; the National Weather Service (NWS) technical memorandum, HYDRO-35, the Rainfall Frequency Atlas of the United States, Technical Paper 40 (TP-40), and the National Oceanic and Atmospheric Administration (NOAA) Atlas 2 documents.[3,4,5] The resolution of the data is as follows: 30 min for the eastern and midwest States covered by the HYDRO-35 and TP-40 documents, 20 min for the 11 western States covered by the NOAA Atlas 2, and 10 min for parts of Southern California.

The State-supplied data base must provide the intensities of 1-h storms for six return periods selected by the State as well as the log-log ratios of short duration storms to long duration storms. Intensities can be generated using any statistical method accepted by the State. Data base format must conform to that specified in appendix D.

Peak Intensity

The manner in which HYDRO determines a rainfall intensity from the default data base follows. The program computes a weighted rainfall intensity averages of the points surrounding a user-supplied latitude and longitude. A rainfall intensity is calculated for a desired frequency and duration using two steps. In the first step, the rainfall is adjusted to the user-supplied frequency or return period using NWS regression equations.[3] This yields a 1- and 24-h rainfall corresponding to the user-defined frequency. The second step adjusts the duration of the storm event (if necessary). HYDRO assumes that the storm duration is equal to the time of concentration (t_c) of the watershed in question.[2] The methods for determining time of concentration are: Soil Conservation Service (SCS) curve number or the kinematic wave for overland t_c; SCS grassy waterway, Manning's formula or HEC-12 triangular gutter for channel t_c; or user-supplied for combined t_c. These will be discussed in more detail later. Finally, the 1- and 24-h rainfall intensities are adjusted to a rainfall intensity associated with the duration using NWS and HYDRO rainfall intensity and frequency regression equations and logarithmic interpolation.[3,6,7]

In this manner, any rainfall with a frequency between 2 and 100 yr and duration between 5 min and 24 h can be considered for analysis. The user is freed from needing the HYDRO-35, TP-40, and Atlas 2 documents, as the intensity calculated by HYDRO represent the data used to create these documents and the accompanying maps.

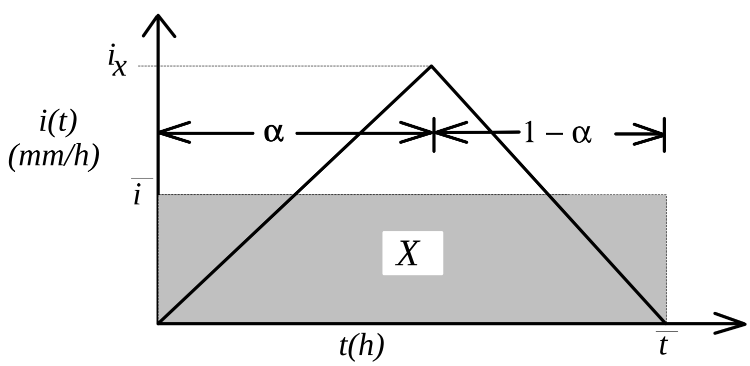
If the State-supplied data base option is exercised, HYDRO uses logic modeled after the CALTRANS program to compute the intensity for a given duration and return period using relationships described in the Technical Operation section.

Hyetographs

To apply the steady-state rainfall intensity to a dynamic condition, the triangular hyetograph method, developed by Yen and Chow is used.[8] This method, discussed in detail later, uses the rainfall intensity, the duration and a regional coefficient (α) to create the hyetograph seen in figure 2. Applications of the results can be as input for other programs that use hyetographs or for analyses such as a Least Total Economic Cost (LTEC) study for storm drain design.[9]

IDF Curves

HYDRO allows the user to create an IDF curve using either of the rainfall data bases discussed earlier. The curve will show, for a user provided frequency, the duration versus intensity for any location in the continental United States. As mentioned earlier, the frequency can be any whole number between 2 and 100 yr and the duration can extend from 5 min to 24 h of rainfall duration. Other HYDRAIN programs can apply these IDF curves as a portion of their input needs.



X = AREA = TOTAL RAIN [mm/Event] = $\dfrac{i_x\,\bar{t}}{2}$

- i_x = twice the average rainfall intensity = $2\,\bar{i}$
- α tabulated in Yen & Chow, 1983

Figure 2. Yen and Chow's triangular hyetograph.

User-Supplied Rainfall Values

Should the user desire to implement a user-specified time of concentration or rainfall intensity values, these can be entered and will override any internally computed values. The user-supplied time of concentration will override the internal time of concentration calculations, and will be the duration that the 1-h, **n** year intensity is adjusted for. A user- supplied rainfall intensity will cause HYDRO to override the data base entirely. It is assumed that the user-supplied rainfall intensity is already adjusted to a desired duration.

PEAK FLOW

HYDRO allows the user to investigate three flow methods: the Rational method, user-supplied regression equations, and the Log Pearson Type III method. Each of these methods produce a single peak or steady state flow value. HYDRO also allows the user to combine the peak flow with the dimensionless hydrograph method so as to consider hydrographic or dynamic flow conditions. The first two flow determination methods, rational and regression, are techniques that are used on ungaged watersheds where runoff is the primary source of flow. The Log Pearson Type III method requires gaged stream flow as the primary input. Each of the three flow methods will be discussed below.

Rational Method

Developed towards the end of the 19th century, the Rational method is still widely used as a method for computing quantities of storm water runoff. Intended for determining runoff from small watersheds, use of the Rational method hinges on several basic assumptions:

- The duration used to determine an intensity from an IDF curve is that corresponding to the time it takes for water to flow from the most remote point in the watershed to the point in question, also known as the time of concentration.

- The intensity of the rainfall is constant and is applied to the entire watershed.

- The runoff coefficient remains constant throughout the storm event.

- The frequency of the peak flow is equal to the frequency of the rainfall intensity.

Since the utility for obtaining a design rainfall intensity has already been created, it becomes easy, when combined with the area and runoff coefficient, to calculate the Rational method peak flow. This value is considered to represent a steady-state flow condition. Once the peak flow has been obtained, a hydrograph can be created if a dimensionless hydrograph and a time lag have been supplied. This allows a dynamic flow condition to be considered, and can be used as input to other HYDRAIN programs.

Regression Equations

Peak flow can also be calculated by using regression equations developed by several State and Federal agencies. The equations are in the form of a log-log formula, where the dependent variable would be the peak flow for a given frequency, and the independent variables may be variables such as area, slope and other physical or site-specific data. The resultant flow is considered to be steady state, although similar to the Rational method, can be used with a dimensionless hydrograph to create a dynamic flow scenario.

Log Pearson Type III Flood Frequency

The third flow method, Log Pearson Type III, allows the user to contemplate the effects of frequency associated with gaged stream flows. The Log Pearson Type III distribution is a three parameter (i.e., mean, standard deviation, and skew coefficient) gamma distribution. A logarithmic transform of the independent variable is made so as to “flatten” the distribution, thus lending it to a variety of stream situations. It has been adopted by the Water Resource Council (WRC) as a standard flood frequency determination method for all Federal agencies.[10,11] The peak flow is assumed by HYDRO to be steady state. As with the other flow determination methods, the peak flow can be used to create a hydrograph from a dimensionless hydrograph. It should be noted that this analysis can be applied to any type of data one wishes to analyze with this distribution.

Hydrographs

Currently, HYDRO computes hydrograph coordinates by multiplying dimensionless hydrograph abscissae by a time lag and by multiplying ordinates by the peak flow. The dimensionless hydrograph coordinates used are either supplied by the user, values derived from a nationwide urban hydrograph study, or use a semi-arid hydrograph relationship.[12] The time lag, which is defined as the time in hours between the center of mass of the excess rainfall to the center of mass of the resulting runoff hydrograph, is either supplied by the user or is computed by HYDRO using a relationship described in the Technical Operation section.

This concludes the system overview section. The next section discusses the technical approach of the topics mentioned above.

TECHNICAL INFORMATION

This section investigates the technical operation of the HYDRO program. The section will be organized in the following manner: Rainfall, including the rainfall data bases, weighted averaging of the intensities, frequency adjustment, time of concentration methods, and duration adjustment; Hyetographs; Peak Flow, including the Rational method, regression equations, and Log Pearson Type III methods; and Hydrographs.

RAINFALL DATA BASES

The default rainfall data base, created specifically for HYDRO, contains precipitation-frequency values for the continental United States. The values are for 2- and 100-yr return periods and 1- and 24-h rainfall durations.

The information used to create the data base came from:

1. The final base values used to compute isohyetal maps for 11 western States.(13) The 11 western States are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming.

2. The tape E17383, obtained from the National Weather Service, contains data for the remaining 37 midwestern and eastern States and the District of Columbia. These are the data that were used to create the HYDRO-35 document.(13)

3. The TP-40 document was used to collect 24-h rainfall intensities for those States not covered by NOAA Atlas 2.

The data base resolution is a 30-min grid in the midwest and east and a 20-min grid in the west except in Southern California, where the resolution is a 10-min grid.

The data were then combined into one file and sorted by latitude and longitude. Graphical and statistical analyses were used to discover any errors or discrepancies in the data. Users should satisfy themselves as to the appropriateness of these data for their application. The logic of the file is such that these data can be locally enriched if the user has access to rainfall data as well as guidance from authorities in the field.

A State can choose to supply its own data base, consisting of 1-h intensities for six State-selected return periods and the log-log slope of the IDF curve. The required data can be generated using any statistical method selected by the State.

LOOKUP AND WEIGHTED AVERAGING OF THE DATA

From the user-supplied site latitude and longitude values, HYDRO enters the data base (default or State-supplied) to find the coordinates most closely associated with those of the site. For the default data base, this is done by initiating a binary search to locate the approximate location of the site in the data set. If the site corresponds to a specific data element, the 2- and 100-yr, 1- and 24-h storm duration, rainfall intensities associated with that data element are read in as variables, and the program moves to the next module (frequency adjustment). Otherwise, HYDRO constructs a one degree by one degree window around the site, and reads in all the data elements (and their corresponding intensities) within that window. The distance between the site and all the elements within the window are calculated, and a weighted average of the rainfall intensities based on distance are obtained. HYDRO will notify the user if there are less than four points in the window. With the 2- and 100-yr, 1- and 24-h duration, weighted average variables, the program will continue to the next module.

For the State-supplied data base, HYDRO identifies up to 50 stations within a 0.25-degree by 0.25-degree window. If a station is within 3 mi of the site, that station's rainfall intensity is used in determining that of the site. Otherwise, a weighted average (based on distance) of the intensities of the stations selected within the window is computed. If a user has identified specific stations for analysis, HYDRO allows selection of up to four stations to be used in calculating the weighted average. HYDRO lists the stations used in the computation so that the user can determine their appropriateness in relation to the site (e.g., a selected station might be located on a slope opposite that of the site).

FREQUENCY ADJUSTMENT

If the default data base is to be accessed, the user can select any return period between 2 and 100 yr. Transforming the frequency of the rainfall intensity from the 2- and 100-yr return periods to a user-defined return period is achieved by using regression equations developed by the NWS and shown below. There are four specific NWS equations and a general equation that was created especially for the HYDRO program.

5-Yr Equation[3]

$$C = (0.278 \times A) + (0.674 \times B) \qquad (1)$$

10-Yr Equation[3]

$$C = (0.449 \times A) + (0.496 \times B) \qquad (2)$$

25-Yr Equation[3]

$$C = (0.669 \times A) + (0.293 \times B) \tag{3}$$

50-Yr Equation[3]

$$C = (0.835 \times A) + (0.146 \times B) \tag{4}$$

General Equation[6]

$$C = (-0.109 + 0.556 \times \log_{10}(n)) \times A + (1.032 - 0.526 \times \log_{10}(n)) \times B \tag{5}$$

Where:

A	=	The intensity for a 100-yr storm with a 1-h duration, mm/h.
B	=	The intensity for a 2-yr storm with a 1-h duration, mm/h.
C	=	The intensity for a user-defined return period with a 1-h duration, mm/h.
n	=	The user-defined frequency or return period, yr.

Equation 5 is used to adjust the frequency for both the 1- and 24-h duration intensities.

If the State data base is to be accessed, the user must either select one of the six "standard" return periods for which data are provided in the data base, or supply the mean 1-h storm, Log Pearson frequency factor, and coefficient of variation so that the 1-h intensity for the user-defined return period can be computed from the relationship:[14]

$$I_{1,rp} = I_{mean} \times (1 + K_j \times C_v) \tag{6}$$

Where:

I_{mean}	=	The mean 1-h storm, mm.
K_j	=	The Log Pearson Type III frequency factor.
C_V	=	Coefficient of variation.

TIME OF CONCENTRATION

Having adjusted the rainfall intensity to the proper return period, the next logical step is to adjust the 1- and 24-h duration to the duration associated with watershed characteristics. The program assumes that this duration equals the time of concentration of the watershed. For IDF curves, pre-set durations are substituted for the time of concentration calculations.

The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. HYDRO approaches time of concentration as the sum of the two. Overland time of concentration is developed by one of two methods; the SCS curve number or by the kinematic wave approach. Channel time of concentration can be developed using one of three methods; SCS grassy waterway channel, Manning's formula or the HEC-12 triangular gutter approach. Finally, the possibility exists for the user to enter a combined time of concentration, thereby overriding all other methods.

SCS Curve Number

The Soil Conservation Service, in Technical Release 55, describes a method for determining the overland time of concentration known as the curve number (CN) method.[15,16] This method is limited to small watersheds ($\leq$ 800 ha) containing consistent land uses and climatological characteristics.

The curve number method begins by subdividing the watershed into smaller watersheds based on land use. HYDRO implements a simplified version of the curve number method by considering seven broad categories of land use: meadows, woods, pasture, crops, residential, urban/right of way and pavement. The next step is to determine the composite type of soil within the watershed. This soil classification helps the method to take into account infiltration. The soil types are categorized as A, B, C, and D, each being defined as:

A: A sandy soil, having deep sand and loess with aggregated silts. The composition is 90 to 100 percent sand/gravel. There is a high infiltration rate of 8 to 11 mm/h.

B: A sand/loam soil, having a shallow loess/sandy loam with a moderate infiltration rate of 4 to 8 mm/h.

C: A clay/loam soil, having low organic content and usually high in clay. It has a slow infiltration rate of 1 to 4 mm/h.

D: A clay soil, having a mixture of heavy plastic clay (90 to 100 percent) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 1 mm/h.

The third step is to determine the Antecedent Moisture Condition (AMC), or as called by HYDRO, the climate. This variable also helps to define the watersheds' soil infiltration capacity. The variables are defined below:

1: A DRY soil, allowing a higher than normal quantity of infiltration, associated with rainfall from 0 to 635 mm/yr.
2: a TYPICAL soil, allowing a normal quantity of infiltration, associated with rainfall from 635 to 1270 mm/yr.
3: a WET soil, allowing a lower than normal quantity of infiltration, associated with rainfall greater than 1270 mm/yr.

These three steps are applied to each subdivided land use, so that a curve number is selected for each land use, and the soil type and climate. The matrix of curve numbers for each possibility of land use, soil and climate is shown in table 1.

Table 1. Curve number matrix.

Land Use	**Curve Number**											
Soil Type	Sand			Sand/Load			Clay/Loam			Clay		
Climate	Dry	Typ	Wet	Dry	Typ	Wet	Dry	Typ	Wet	Dry	Typ	Wet
Meadow	15	30	50	38	58	77	52	71	88	61	78	93
Woods	20	36	56	40	60	79	55	73	89	62	79	93
Pasture	30	49	69	50	69	86	62	79	93	69	84	96
Crops	41	61	80	55	73	89	64	81	95	69	84	96
Residential	42	62	81	56	74	90	66	82	95	72	86	97
Urban	56	74	90	69	84	96	78	90	98	82	92	98
Pavement	82	92	98	82	92	98	82	92	98	82	92	98

A composite curve number for the entire watershed is determined by taking a weighted average of the subdivided areas and curve numbers as shown below:

$$CN = \frac{\sum \left[CN_i \times A_i \right]}{\sum A_i} \tag{7}$$

Where:

CN = The composite curve number for the watershed.
CN_i = The curve number associated with each subdivided land use, the watershed soil type and climate.
A_i = The subarea associated with each subdivided land use, the total area of the watershed is therefore equal to the sums of the subareas.

HYDRO also allows the user to enter their own curve number value. This user-defined curve number will override the computed curve number process and will be used by HYDRO in the subsequent step.

The composite curve number (or user-defined curve number) is next transformed into an intermediate empirical value using the formula:

$$S = \frac{1000}{CN} - 10 \tag{8}$$

Where:

S = An intermediate empirical value.
CN = The composite or user-defined curve number defined above.

Finally, the SCS overland time of concentration is calculated as:

$$t_{co} = \frac{L_o^{0.8} \times (S + 1)^{0.7}}{441 \times S_o^{0.5}} \tag{9}$$

Where:

t_{co} = The overland time of concentration, h.
L_o = The overland length, defined as the length from the most remote point of the watershed to the outlet or beginning of channel flow, m.
S = The intermediate empirical coefficient, defined above.
S_o = The average overland slope, percent.

<u>Kinematic Wave</u>

The alternative overland time of concentration method that is found in HYDRO is the kinematic wave approach. It is used as defined in HEC-12 (FHWA, 1984) and based on research conducted for the Maryland State Highway Administration and the FHWA.(17) Although the kinematic wave theory is not found in HEC-19, it was felt that it was appropriate to include it in HYDRO so as to provide the user with an alternative to the curve number method.

The kinematic wave approach recognizes that overland flow can be simulated by a moving film of turbulent flow over the watershed surface. The time of concentration for this wave can be expressed as a function of flow length and slope, Manning's surface roughness factor, and the rainfall intensity. The basic formula is given as:

$$t_{co} = \frac{418 \times L_o^{0.6} \times n^{0.6}}{S_o^{0.3} \times i^{0.4}} \tag{10}$$

Where:

t_{co}	=	The overland time of concentration, s.
L_o	=	The overland length, defined as the length from the most remote point of the watershed to the outlet or beginning of channel flow, m.
n	=	Manning's friction value for a waterway.
S_o	=	The average overland slope, m/m.
i	=	The rainfall intensity, for a desired frequency or return period, mm/h.

Initially, HYDRO uses the 1-h rainfall intensity (already adjusted for the desired frequency) and will use equation (10) to compute an initial time of concentration. Should the initially calculated time of concentration equal one hour, the analysis is complete and HYDRO continues to the next module. If this is not the case (which is more likely), the initially calculated time of concentration is assumed to be the duration, and using equations discussed later, a corresponding intensity is determined.

This intensity is substituted into equation (10), and a second estimate of time of concentration is calculated and compared to the initial estimate. If necessary, a third intensity is determined and substituted back in to the equation. The process is iteratively repeated until the time of concentration estimates converge. HYDRO will use a time of concentration value that is at less than 1 percent different than the previous estimate; or select a minimum value of 5 min or a maximum value of 24 h. This value of time of concentration is converted to hours and used in the subsequent program modules.

SCS Grassy Waterway

The SCS grassy waterway is a subset of the Upland method described in the SCS handbook.[15] It describes a linear relationship between velocity and watershed slope when the variables are placed on a log-log graph. To apply the method to the HYDRO program, regression curve fitting techniques were used to determine the equation of this line.[6] The SCS grassy waterway equation is given as:

$$V = 0.455 \times S_c^{0.504} \tag{11}$$

Where:

V	=	The channel velocity, m/s.
S_c	=	The average slope of the channel, percent.

Manning's Formula

HYDRO allows open channel and gutter time of concentration to be calculated using Manning's formula for velocity:

$$V = \frac{1}{n} \times R_h^{0.67} \times S_c^{0.5} \tag{12}$$

Where:

V	=	The weighted average velocity occurring within a channel's cross sectional area, m/s.
R_h	=	The hydraulic radius of a channel (channel area divided by wetted parameter), m.
S_c	=	The friction slope (assumed to be the average channel slope), m/m.
n	=	Manning's friction value for the channel.

Triangular Gutter Section

The triangular gutter equation is a special case of the regular Manning's formula. It was described in HEC-12.[(2)] The equation describes flow in wide, shallow, triangular channels. The area of the gutter and the hydraulic radius are a function of the spread and the roadway cross slope. In other words, a channel with the shape shown in figure 3 is assumed.

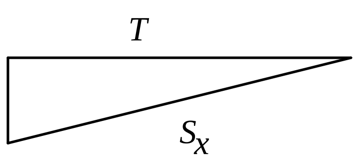


Figure 3. Triangular gutter section.

Substituting basic geometric relationships, derived from figure 3 into equation (12) yields:

$$V = \frac{0.75}{n} \times S_c^{0.5} \times S_x^{0.67} \times T^{0.67} \tag{13}$$

Where:

V	=	The velocity occurring within a gutter, m/s.
n	=	Manning's friction value for the channel.
S_c	=	The average channel slope, m/m.
S_x	=	The roadway cross slope, m/m.
T	=	The spread occurring in the gutter section, m.

Combining the velocity (calculated using one of the three channel time of concentration methods above) with the channel length, the channel component of the time of concentration is calculated:

$$t_{cc} = \frac{L_c}{V \times 3600} \tag{14}$$

Where:

t_{cc}	=	The channel time of concentration, h.
L_c	=	The length of the channel, m.
V	=	The channel velocity, calculated using one the methods discussed above.

Combining Overland and Channel Time of Concentrations

The time of concentration for the watershed is calculated as the sum of the overland and channel constituents:

$$t_c = t_{co} + t_{cc} \tag{15}$$

Where:

t_c	=	The combined time of concentration of the watershed, h.
t_{co}	=	The overland time of concentration, h.
t_{cc}	=	The channel time of concentration, h.

The combined time of concentration will be assumed to be equal to the duration by HYDRO. Should a user-defined time of concentration be entered, it will override the calculated values and is considered to be the duration by the program.

ADJUSTING RAINFALL INTENSITY FOR DURATION

If the default data base is used in the analysis, transformation of the 1- and 24-h rainfall intensities to the intensity associated with the time of concentration, just calculated, is achieved using NWS and HYDRO rainfall intensity and frequency regression equations and logarithmic interpolation. The NWS equations are from the HYDRO-35 memorandum.[3] There are four equations for transforming the 1-h intensity to rainfall intensities less than 1 h:

5-Min Equation[6]

$$i_{5\min} = 13.5 \times i_{1h}^{0.635} \tag{16}$$

10-Min Equation[3]

$$i_{10\min} = 0.59 \times i_{15\min} + 0.41 \times i_{5\min} \tag{17}$$

15-Min Equation[6]

$$i_{15\min} = 4.46 \times i_{1h}^{0.817} \tag{18}$$

30-Min Equation[3]

$$i_{30\min} = 0.49 \times i_{1h} + 0.51 \times i_{15\min} \tag{19}$$

Where:

$i_{5\text{ min}}$	=	The 5-min rainfall intensity derived from a 1-h rainfall intensity and having a user-defined return period, mm/h.
$i_{1\text{ h}}$	=	The 1-h rainfall intensity having a user-defined return period, mm/h.
$i_{10\text{ min}}$	=	The 10-min rainfall intensity derived from the 5- and 15-min rainfall intensities and having a user-defined return period, mm/h.
$i_{15\text{ min}}$	=	The 15-min rainfall intensity derived from a 1-h rainfall intensity having a user-defined return period, mm/h.
$i_{30\text{ min}}$	=	The 30-min rainfall intensity derived from the 15-min and 1-h rainfall intensities and having a user-defined return period, mm/h.

If the duration is less than one hour, and not equal to one of the four equations above, a linear interpolation routine is used to determine the intensity value.

If the duration is greater than 1 h, but less than 24 h in length, a general equation is used to transform the rainfall intensity. The equation uses a log-log interpolation between duration and intensity as follows:

$$i_{d,rp} = i_{1,rp} \times D^{\left[\log_{10}\left(i_{24,rp}\right) - \log_{10}\left(i_{1,rp}\right)\right] / \log_{10}(24)} \tag{20}$$

Where:

$i_{d,rp}$	=	Intensity for a specified duration and return period, mm/h.
$i_{1,rp}$	=	Intensity for a 1-h storm and the specified return period, mm/h.
D	=	Duration, h.

$i_{24,rp}$ = Intensity for a 24-h storm and the specified return period, mm/h.

If the State-supplied data base is used, the intensity for the appropriate duration is calculated from the relationship:[13]

$$I_{d,rp} = I_{1,rp} \times D^{r} \tag{21}$$

Where:

$I_{d,\,rp}$ = Intensity mm/h for a specified duration and return period.
$I_{1,\,rp}$ = Intensity mm/h for a 1-h storm and the specified return period duration, h.
D = Duration, h.
r = Log-log slope of the IDF curve.

The end result of this process is a rainfall intensity that reflects watershed characteristics and a specified storm duration and frequency. Should the user wish to override this intensity, HYDRO allows a user-defined rainfall intensity to be entered. As mentioned above, this value represents a rainfall intensity that has been adjusted for frequency and duration by the user.

HYETOGRAPH

The triangular hyetograph concept, used in HYDRO, is based on the work of Yen and Chow for the FHWA.[8] They felt that a typical rain event could be described using a triangular shape defined by three parameters. The first parameter is the “apex” of the triangle, equal to twice the peak rainfall intensity. The “base” of the triangle, equal to the duration of the storm, is the second parameter. The last parameter is the time to the peak intensity, and is based on a localized coefficient shown on a map in the Yen and Chow document. The total volume of rainfall is found by using basic geometric principles. The triangular hyetograph is shown earlier in figure 2.

To apply the methodology, HYDRO needs these three parameters. HYDRO will either use calculated or user-supplied intensity and duration values to satisfy the need for the first two parameters. The final parameter is found using an internal table containing coefficients for 17 regions which make up the continental United States. The region is determined from the user-supplied latitude/longitude of the site.

IDF CURVE

The Intensity-Duration-Frequency curve is produced, for a given frequency and location, by calculating the rainfall intensities associated with the 5-, 10-, 15-, 30-min, and 1-, 2-, 4-, 8- and 24-h durations. Specifically, a location and the rainfall data base (default or State-supplied) are used to retrieve the appropriate 1- and 24-h rainfall intensities. Next, the rainfall intensities are adjusted (if necessary) to a user-supplied frequency using equations (1) through (5) or equation

(6). Finally, equations (16) through (20) or equation (21) are used to calculate the rainfall intensities.

RATIONAL METHOD

The Rational method is perhaps one of the most widely used “tools” for determining runoff resulting from a storm event. Although newer methods of determining runoff have been created, the simplicity of the Rational method has stood the test of time. The Rational method equation is of the form:

$$Q = K \times C \times i \times A \tag{22}$$

Where:

Q	=	The peak flow, m^3/s.
K	=	Constant, 0.00276.
C	=	The runoff coefficient.
i	=	The rainfall intensity, mm/h.
A	=	The area of the watershed, ha.

HYDRO applies the Rational method by first subdividing the watershed area into one of the seven subareas defined earlier: meadow, woods, pasture, crops, residential, urban/highway right of way and pavement. These are analogous to the land uses found in HEC-12.[(2)]

Each subarea has a corresponding default runoff coefficient. These default coefficients are shown in table 2. If they desire, the user may substitute their own runoff coefficient, thereby overriding the internal values.

Table 2. Default runoff coefficients.

Land Use	**C Value**	**Land Use**	**C Value**
Meadows	0.2	Residential	0.4
Woods	0.2	Urban & Hwy ROW	0.7
Pasture	0.3	Pavement	0.9
Crops	0.3		

Once each subarea has been assigned an area and a corresponding runoff coefficient, a weighted runoff coefficient for the entire watershed is computed:

$$C = \frac{\sum \left(C_i \times A_i\right)}{\sum A_i} \tag{23}$$

Where:

C	=	The weighted runoff coefficient for the entire watershed, having no dimension.
C_i	=	The runoff coefficient associated with each subarea.
A_i	=	The subarea associated with each subdivided land use, ha. The total area of the watershed is equal to the sum of the subareas.

The rainfall intensity, used in the Rational method, will be a function of location, frequency and duration of the storm. To determine the rainfall intensity, HYDRO repeats the calculations that produced a steady state rainfall intensity value. First, the rainfall intensity is adjusted to a user-defined frequency. Since the Rational method assumes that duration and time of concentration are equal, the time of concentration methods discussed earlier will be used again. As an alternative to this, the user can assign a value for time of concentration. Finally, the rainfall intensity is adjusted from a one-hour duration, to the duration just calculated. If the user supplies a rainfall intensity, it will override any internally calculated value.

HYDRO enters the weighted runoff coefficient, rainfall intensity and watershed area into equation (22), and calculates the Rational method peak flow.

REGRESSION EQUATIONS

A more sophisticated analysis of flow at ungaged watershed can be achieved through the use of regression equations. These equations related peak flow of a specified frequency to physical or site-related factors. The typical equation is:

$$Q_p = a \times \prod_{i=1}^{n} X_i^{b_i} = a \times X_1^{b_1} \times X_2^{b_2} \cdot \cdot \cdot X_n^{b_n} \tag{24}$$

Where:

Q_p	=	The equation peak flow, m^3/s.
a	=	The constant, usually a translation factor.
X_i	=	The independent variables (parameters) for the watershed.
b_i	=	The exponential coefficients associated with each independent variable.
n	=	The number of independent variables.

The equation is usually developed by regression using logarithms of the dependent and independent variates for a specific region or State. The FHWA has a document that describes regression equations used to calculate runoff from small watersheds in 24 hydrophysiographic regions.[(1)] The FHWA equations were developed for a 10-yr flood frequency and have 3, 5, or 7 independent variables. The United States Geological Survey (USGS) has conducted a nationwide study that developed three and seven parameter regression equations.[(12)] More recent work has concentrated on developing regional equations.[(18)] The interested reader is referred to the literature for more information on typical coefficients and variables to be used with these equations.[1]

LOG PEARSON TYPE III FLOOD FREQUENCY

The Log Pearson Type III method is designed to be applied on watersheds with gaged stream flows. It was chosen by the Water Resources Council for its ability to statistically fit (Pearson's distribution is a three parameter solution of a gamma distribution) a variety of flood frequencies.[10,11] Log Pearson Type III is the flood frequency standard for agencies of the Federal Government.

HYDRO applies Log Pearson Type III by first considering the relative location of the watershed outlet to that of the gaging station from where the peak stream flows were obtained. If the watershed outlet is at the same location as the gauging station, then no adjustments to the flow data are necessary, and HYDRO continues on towards the next module. An example of this occurrence is demonstrated in figure 4.

If the watershed outlet is not at the same location as the gaging station, the annual peak stream flows must be adjusted. In this case, the watershed outlet is either <u>UPSTREAM</u> or <u>DOWNSTREAM</u> from the gaging station and HYDRO uses the relative areas of the watershed and station to estimate the fractional contribution of the watershed's runoff to that of the station area. This can be seen in figure 4 and is described mathematically as:

$$Q_{ia} = Q_i \times \left[\frac{A_w}{A_g}\right]^{aexp} \tag{25}$$

Where:

Q_{ia}	=	The adjusted peak annual flow, m^3/s.
Q_i	=	The original peak annual flow, m^3/s, this is the flow obtained from the gauging station.
A_w	=	The area of the watershed, ha.
A_g	=	The area of the gauging station, ha.
aexp	=	Area adjustment exponent.

[1]The results of a nationwide compilation of USGS equations are found in the NFF program module accessible elsewhere within the HYDRAIN system.

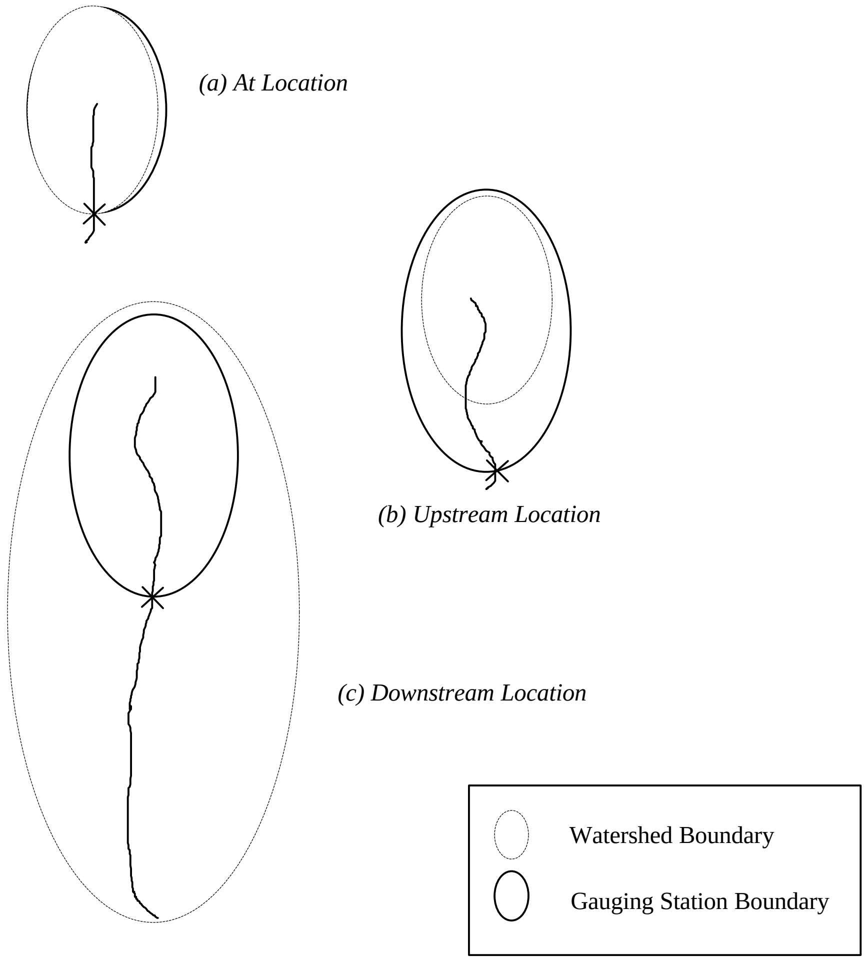


Figure 4. Relative watershed locations.

If the value of the area adjustment exponent is equal to 1.0, then the respective watersheds are topographically similar. After the proper locational adjustments (if any) have been made, the peak annual stream flows are transformed using a logarithmic function. The intention is to decrease the relative variability of the stream flow distribution.

The three parameters of the distribution are the sample mean, standard deviation, and the skew coefficient. HYDRO defines these parameters as:

Sample Mean; (geometric mean).

$$\overline{Q_L} = \frac{\sum \log_{10}(Q_i)}{n} \tag{26}$$

Standard Deviation;

$$S_L = \sqrt{\frac{\sum_{i=1}^{n} \left[\log_{10}(Q_i) - \overline{Q_L}\right]^2}{n - 1}} \tag{27}$$

Skew Coefficient;

$$G_L = \frac{n \times \sum_{i=1}^{n} \left[\log_{10}(Q_i) - \overline{Q_L}\right]^3}{(n - 1) \times (n - 2) \times S_L^3} \tag{28}$$

Where:

G_L	=	The skew coefficient for the sample of peak annual stream flow values.
S_L	=	The standard deviation of the peak annual stream flow values, $\log_{10}m^3/s$.
$\overline{Q_L}$	=	The mean of the log transformed peak annual stream flows, $\log_{10}m^3/s$.
Q_i	=	The peak annual stream flow samples, $\log_{10}m^3/s$.
n	=	The period of record for the gaged stream flows, yr. It is strongly suggested that an adequate number of years be used. The WRC recommends 30 or more records; however, HYDRO has been tested successfully with as few as seven.

The computed skew coefficients are sensitive to extremes in stream flow and to a small number of records. For this reason, HYDRO allows the user to override the computed skew coefficient with a user-supplied regional skew coefficient value. For the interested user, WRC Bulletin 17B provides a map of these regional skew coefficient values.(11)

HYDRO calculates a form of the Incomplete Gamma Function using the methodology outlined by Croley.(19) Simply put, Croley's methodology solves Pearson's integral for a probability that is a function of flow. To begin this analysis, HYDRO first defines three translation coefficients:

$$\alpha = \left[2 \times G_L\right]^2 \tag{29}$$

$$= \frac{\left[S_L \times G_L\right]}{2} \tag{30}$$

$$F \quad = \overline{Q_L} \; - \; \frac{2 \times S_L}{G_L} \tag{31}$$

Where:

α	=	The first Croley translation coefficient, alpha.
ß	=	The second Croley translation coefficient, beta.
	=	The third Croley translation coefficient, delta.

HYDRO next defines the upper interval of Pearson's integral as:

$$t \;\; = \frac{\log_{10}Q \quad - \quad}{\qquad\qquad} \tag{32}$$

Where:

t	=	The -quantile point for some logarithmic transformed stream flow, Q .
Q	=	A stream flow in the distribution defined by Q_L, S_L and G_L, m^3/s.
	=	The translation coefficient, delta, defined above.
ß	=	The translation coefficient, beta, defined above.

Pearson's integral, is defined as:

$$= \int_0^t \frac{1}{(\alpha)} \times t^{(\alpha - 1)} \times e^{-t} \times dt \approx P(Q \leq Q \;) \tag{33}$$

Croley developed a first order approximation of the integral which he gives as:

$$P(Q \leq Q \;) \approx \sqrt{\frac{\alpha + 5}{2 \times} \times \frac{(\alpha + 4)! \times \alpha}{\alpha!} \times \left[\frac{t}{\alpha + 5}\right]^{\alpha} \times \left[\frac{1}{\alpha + 5}\right]^{5} \times}$$

$$\exp\left[-t \quad + \alpha + 5 - \frac{1}{12 \times (\alpha + 5)} + \frac{1}{\left(360 \times (\alpha + 5)\right)^3}\right] \times$$

$$\sum_{j=0}^{14} \left[\frac{t^j}{\prod (\alpha + j)}\right] \tag{34}$$

Where:

P(Q≤Q)	=	The probability that the flow Q is equal or greater than some flow, the inverse of which is that flow's return period.
α	=	Croley's translation coefficient, defined above.
	=	The value of pi, truncated in HYDRO to be 3.1415927.
t	=	The upper bounds of Pearson's integral, defined above.
j	=	An integer variable used in the summation.

HYDRO will enter two values for Q into equation (34) (with the two values of Q initially equaling the maximum and minimum values for the range of Q_i), which will return two associated probabilities. Since the user-defined return period for the peak flow can be expressed as a probability:

$$P(Q_p) = \frac{1}{n} \tag{35}$$

Where:

$P(Q_p)$	=	The probability associated with the user-defined return period, yr^{-1}.
n	=	The user-defined return period, yr.

The program uses an elimination scheme algorithm to converge to a flow that is a function of the user-defined probability. This is the flow that is used by HYDRO as the peak flow value.

There are two potential areas of trouble when using equation (34). First, the upper interval of the integral must satisfy the condition $0 \leq t \leq \infty$. If the upper interval value becomes negative, HYDRO will recognize this condition and will not attempt to solve the integral. The second trouble area is a stream flow distribution that can not be adequately solved using a first order approximation. In this case, the result will be that the Q will converge towards infinity. Should either occur, HYDRO will use WRC-17B equations as an alternative.

The alternative method is based on the fact that the value for peak flow is usually within five percent of a value derived by a table.(11) The function relates the skew coefficient to the normal deviate, and produces a skew based on a user-defined probability:

$$K = \frac{2}{G_L} \times \left[\left[1 + \frac{G_L \times Z}{6} - \frac{G_L^2}{36} \right]^3 - 1 \right] \tag{36}$$

Where:

K	=	The skew value based on a user-defined frequency.
G_L	=	The skew coefficient for the sample of peak annual stream flow values.
Z	=	The normal deviate, that is approximated by:

$$Z = 4.91 \times \left[(1 - P)^{0.14} - P^{0.14}\right] \tag{37}$$

P	=	The user-defined probability, defined as the inverse of the return period.

Once the skew has been estimated, it can be combined with the mean and standard deviation to calculate the peak flow for a given return period. This equation is given as:

$$Q_p = 10^{\left(\overline{Q_L} + K \times S_L\right)} \tag{38}$$

Where:

Q_p	=	The peak flow for the stream, m^3/s, based on a user-defined return period.
$\overline{Q_L}$	=	The mean of the log transformed peak annual stream flows, $\log_{10} m^3/s$.
K	=	The skew value based on a user-defined frequency.
S_L	=	The standard deviation of the peak annual stream flow values, $\log_{10} m^3/s$.

The value derived by using Croley's equation or, if required, by the WRC-17B approximation is taken by HYDRO as representing the Log Pearson Type III peak flow value of a gaged stream.

HYDROGRAPH FORMATION

HYDRO uses two dimensionless hydrograph methods for generating a hydrograph representing the average runoff for a particular peak flow.[2] These methods are the USGS nationwide urban method and the semi-arid method. Within HYDRO, both are optional and require the user to access them using the **DHY** and **AHY** commands.

USGS Nationwide Urban Hydrograph

The nationwide urban method uses information developed by the USGS that approximates the shape and characteristics of hydrographs. Information required for using this method are: (1) dimensionless hydrograph ordinates; (2) time lag; and (3) peak flow. HYDRO can use either

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[2]Hydrographs can also be generated using the NFF program module accessible elsewhere within the HYDRAIN system.

default dimensionless hydrograph coordinates or coordinates supplied by the user to define the shape of the hydrograph. Table 3 lists default values derived from the nationwide urban hydrograph study.(12)

Table 3. Default USGS dimensionless hydrograph coordinates.

Abscissa	Ordinate	:	Abscissa	Ordinate
0.0	0.00	:	1.3	0.65
0.1	0.04	:	1.4	0.54
0.2	0.08	:	1.5	0.44
0.3	0.14	:	1.6	0.36
0.4	0.21	:	1.7	0.30
0.5	0.37	:	1.8	0.25
0.6	0.56	:	1.9	0.21
0.7	0.76	:	2.0	0.17
0.8	0.92	:	2.1	0.13
0.9	1.00	:	2.2	0.10
1.0	0.98	:	2.3	0.06
1.1	0.90	:	2.4	0.03
1.2	0.78	:	2.5	0.00

The abscissae are multiplied by the time lag between the centroid of the rainfall and the centroid of the runoff which is either supplied by the user or computed in accordance with the following relationship:(12) [3]

$$TL = \frac{L^{0.62} \times (13 - BDF)^{0.47}}{1630 \times S^{0.31}} \tag{39}$$

Where:

TL	=	Time lag, h.
L	=	Main channel length, m.
S	=	Main channel slope, m/m.
BDF	=	Basin development factor (a value ranging from 0 to 12, where 0 represents an undeveloped basin and 12 represents a basin consisting 100 percent of storm sewers, lined channels, or curb and gutter streets).

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[3] Typically, the time lag is about 60 percent of the time of concentration and this relationship can be used to estimate user-supplied TL values based on time of concentration.

The ordinates are multiplied by the peak flow which is calculated by HYDRO according to one of the previously described methods (i.e., Rational method, regression equations, or Log Pearson Type III) or with peak flows provided by the user.

Semi-Arid Hydrograph

The USGS developed the semi-arid method for sites that exhibit a single peak hydrograph shape that is common to small, drier watersheds under 39 km^2.[20] Information required for using this method are: (1) dimensionless hydrograph ordinates; (2) semi-arid volume; and (3) peak flow. HYDRO uses default dimensionless hydrograph to define the shape of the hydrograph. Table 4 lists these default values derived from the semi-arid hydrograph study.[20]

Table 4. Semi-arid dimensionless hydrograph coordinates.

Abscissa	Ordinate	:	Abscissa	Ordinate
0	0.0	:	14	55
3	5.6	:	18	38
5	13	:	23	23
7	25	:	30	23
10	49	:	40	12
11	57	:	50	5.2
12	60	:	60	2
13	59	:	70	0.5

To obtain a time value, the abscissae are multiplied equation by equation (40):

$$t_i = \frac{abscissa_i}{970} \times \left[\frac{V_n}{Q_p} \right] \tag{40}$$

Where:

t_i	=	The time value at abscissa i, min.
V_n	=	The volume of the hydrograph, based on the basin area and the return period, m^3.
Q_p	=	The peak flow, m^3/s.

The flows corresponding to these times are calculated using equation (41):

$$q_i = ordinate_i \times \left(\frac{Q_p}{60} \right) \tag{41}$$

Hydrographs developed with either method can generate HYDRO output that is available as input for HYDRA and HY8. These program use the hydrographs to evaluate dynamic responses of culverts and storm drain systems.

This concludes the technical overview of the HYDRO program. The next section will provide instructions for its use in the HYDRAIN system.

USER DOCUMENTATION

Effective use of HYDRO requires an understanding of the interaction between user and the software. While the previous chapter described what HYDRO does, this chapter explains how one communicates with the software to achieve desired results.

THE COMMAND APPROACH - ORGANIZING THE DATA

HYDRO operates through the command language concept. This means that data entry and data analysis are all dictated by user-supplied commands. A command is a very specific entity that describes one basic task that HYDRO can recognize. There is only a set number of commands in HYDRO's vocabulary and they must each follow a specific format. Currently there are 27 commands that HYDRO can recognize, although this number is subject to change as long as improvements are being made to HYDRO. Appendix C includes a complete list, to date, of these commands along with their definitions and format specifications.

Commands provide the instructions and necessary data for performing hydrologic analyses. The collection of commands which define a HYDRO job are collectively referred to as a command string. These commands may be arranged in almost any order, provided they satisfy a few, simple requirements. The only requirements are that the **JOB** command must be the first non-**REM**ark command to appear in the string, one of the three branch commands (**RFL**, **IDF**, or **FLW**) must be the second, and the **END** command must occur last in the string. All other commands can appear in any order within the string. Commands operate in “free format” fashion; that is, a space [ ] or a comma [,] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical). Continuation of a command with many or extremely lengthy variables is achieved by simply typing in the data; the editor will wrap the data onto a second line with the same command ID. A brief glossary of all the commands is shown in table 5. Appendix C provides detailed descriptions, formatting templates, and special notes for each command.

Table 5. Glossary of commands.

Command	Description
AHY	- signal use of semi-**A**rid **HY**drograph.
APM	- specify a user-supplied regional **A P**ri**M**e value for a hyetograph.
BAS	- specify **BAS**in land use areas.
CAL	- specify **CAL**ifornia (state) rainfall data base if NWS is not used.
CRP	- specify **C**alifornia (state) **R**eturn **P**eriod information.
DHY	- signal use of **D**imensionless **HY**drograph.
END	- signal the **END** of the command string.
FLW	- specify the method for determining peak **FL**o**W**.
GFL	- specify **G**age **FL**ow for Log Pearson Type III analysis.
IDF	- signal computation and plotting of an **IDF** curve.
JOB	- initiate **JOB** and specify a job title.
LOC	- specify the **LOC**ation of a site using latitude and longitude.
LPA	- specify constants for **L**og **P**earson Type III **A**nalysis.
MOF	- signal computation of **M**aximum **O**bservable **F**lood.
QAA	- flow **A**rea **A**djustment for Log Pearson Type III.
QPK	- user-supplied **P**ea**K** flow, **Q**.
REM	- to provide **REM**arks or comments.
RFL	- specify computation of single **R**ain**F**al**L** intensity or hyetograph.
RGR	- specify **R**e**GR**ession coefficients for peak flow computations.
RPD	- specify **R**eturn **P**erio**D** for frequency-dependent calculations.
RTL	- specify **R**a**T**iona**L** method runoff coefficients.
STN	- retrieve rainfall data for a **ST**atio**N** from a state data base.
TCC	- specify data for **T**ime of **C**oncentration for **C**hannel flow.
TCO	- specify data for **T**ime of **C**oncentration for **O**verland flow.
TCU	- **U**ser-supplied **T**ime of **C**oncentration.
TLG	- specify **T**ime **L**a**G** or information to compute time lag.
UIT	- **U**ser-supplied rainfall **I**n**T**ensity of a 1-h storm.

Figure 5 shows an example command string, broken down into its command name and accompanying data fields, with an explanation of each command used. Note that the **JOB** command is first. This provides a means of identifying and/or describing the job. The next command is the **FLW** command which determines that a flow analysis (rather than a rainfall or IDF analysis) is to be performed). For this case, the Rational method will be used to calculate peak runoff, as specified by the value of one, used as the first parameter. The **RTL** command is the third command; it is used to specify the runoff coefficients for the seven classes of land use (i.e., meadow, woods, pasture, crops, residential, urban/highway, and pavement). The **BAS** command is the fourth command in the data set. It specifies the different land use areas. Site-specific data are entered in the **TCO** command to compute the overland time of concentration for a runoff length of 400 m, 0.02 m/m slope, a soil type of B, and an antecedent moisture condition of 3. The **TCC** command provides the data needed to compute the channel time of concentration for a channel length of 150 m and a slope of 0.01 m/m. Location of the site is defined by providing the latitude and longitude with the **LOC** command. This location is used to access rainfall data for the region from the NWS data base. Finally, the return period of 50 yr is specified in the **RPD** command.

HYDRO Command	Data	Comments
JOB	Command Example	The title of the HYDRO job.
FLW	1	Use Rational method to compute peak flow.
RTL	* * * 0.35 * * 0.95	Set default runoff coefficients for meadows, woods, pasture, residential, and urban/highway right-of-way (land uses 1, 2, 3, 5, and 6). For the crops and pavement areas, override the defaults–entering user-supplied values of 0.35 and 0.95, respectively.
BAS	0 0 0 50 0 1.5 4.0	Specify areas associated with the land uses. (Note that the zeros serve as place holders for land uses not present in the data.)
TCO	400.0 0.02 B 3	Specify data to compute overland time of concentration.
TCC	150.0 0.01	Specify data to compute channel time of concentration.
LOC	35 14 80 50	Latitude and longitude of site.
RPD	50	50-yr return period.
END		Terminates the HYDRO run and prints the results.

Figure 5. Example of a command string.

Figure 6 shows the required and optional commands for each of the three analysis branches. The order of the individual commands is unimportant except for the first, second, and last non-**REM**ark command. A **REM**ark command can appear anywhere within a command string.

As shown in figure 6, two options are available within the Rainfall Analysis branch. The user can instruct HYDRO to compute a single rainfall intensity or a hyetograph by specifying the appropriate option number with the **RFL** branch command. Information related to the basin area, time of concentration, basin location, and return period are provided by the user on the appropriate cards. The **TCO**/**TCC** commands can be replaced with the **TCU** command if the user wishes to supply the combined overland and channel time of concentration. If the user supplies an intensity using the **UIT** command, then neither the time of concentration commands nor the **LOC**ation command need be used. The **CAL** command (with or without the **CRP** and **STN** commands) should appear in the command string if using the State rainfall data base.

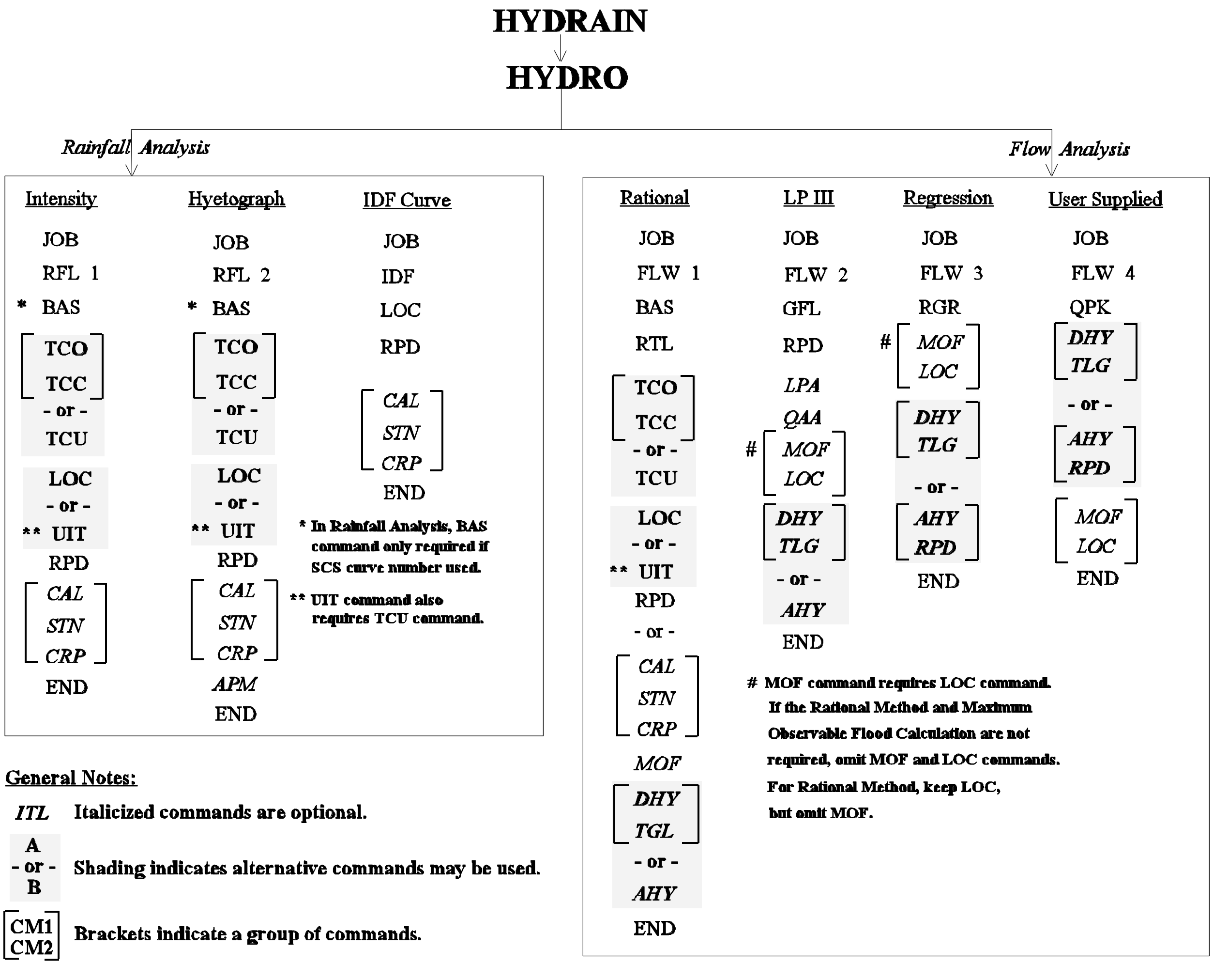

Figure 6. HYDRO footprints.

The second branch within HYDRO generates an IDF curve. Besides the **JOB**, **IDF** branch command, and **END** commands, **LOC** and **RPD** are the only other commands required. As in the rainfall analysis branch, if the user supplies an intensity with the **UIT** command, then the **LOC** command does not need to be used in the command string.

The Flow Analysis branch has four options, as indicated in figure 6. The user can indicate computation of peak flow using the Rational method, Log Pearson Type III analysis, or user-supplied regression equation by specifying the appropriate option number with the **FLW** branch command. HYDRO will compute a hydrograph if the **DHY** and **TLG** or the **AHY** commands are present. Option 4 allows the user to supply the peak flow with the **QPK** command for use in deriving the hydrograph. In addition, with any of the four options, the user can specify that the Maximum Observable Flood be computed by including the **MOF** command in the command string. The **MOF** command requires that the **LOC** and **BAS** commands also be present.

THE HYDRAIN ENVIRONMENT

For those users who have obtained HYDRO as part of the FHWA's **HYDRAIN** package, consult the HYDRAIN documentation for information on how to use the software system.

There are three methods by which HYDRO can be run. Two of these are within the HYDRAIN environment. The first method is to run HYDRO from the HYDRAIN editor. This allows the user the option of immediate review, editing capabilities. The second method is to run HYDRO from the HYDRAIN shell using the **Execute** option. The third method is to execute HYDRO from the DOS prompt. Discussion of all three of these options is within the HYDRAIN documentation.

Upon completion of the run, the output file is automatically assigned an **.LST** filename extension. The output file contains an echo of the input data and the results. The output may contain messages describing warnings or errors encountered during execution. These messages are useful in debugging an input data set.

HYDRO produces four other output files used in conjunction with other programs in the PFP system. These optional output files have the following extensions:

- QT - This extension contains the ordinates of a hydrograph (ie: flow (Q) versus time (T)). The file is generated by HYDRO and, at user option, can be incorporated into the other HYDRAIN Engineering programs (i.e., into HYDRA using the **UHY** command).

- IDF - This extension contains the ordinates of an Intensity-Duration-Frequency (IDF) curve (for a duration from 5 min to 24 h). The file is generated by HYDRO and, at user option, can be incorporated into the other HYDRAIN Engineering programs (i.e., into HYDRA using the **RAI** command).

- Q - This extension contains the ordinates of flow (Q) versus return period. It is created during Log Pearson Type III analysis.

- HYE - This extension contains the ordinates of a hyetograph (i.e., rainfall intensity (I) versus time (T)). The file is generated by HYDRO.

An additional program developed by the California Department of Transportation, IDF, can be used to analyze the state data base as an alternative to HYDRO. It can be accessed by invoking the DOS SHELL option within HYEDT or HYDRAIN and typing IDF at the DOS prompt.

APPENDIX A: BENCHMARK EXAMPLES

The following examples serve to illustrate the types of analyses that HYDRO can perform. While these examples are not intended to illustrate all of the options within HYDRO, they are intended to satisfy the following four objectives:

1. Provide guidance for creating command strings.
2. Demonstrate uses for many of the commands.
3. Provide information on how to set up a problem.
4. Demonstrate what to expect for output.

The six examples presented here illustrate the three major types of analyses that HYDRO performs. Examples 1, 2, and 3 illustrate rainfall analyses, example 4 illustrates IDF curve generation, and examples 5 and 6 illustrate flow analyses. Specific options addressed by each example are listed below:

1. Single rainfall intensity calculation using the Pooled Fund data base.
2. Single rainfall intensity calculation using California's State data base.
3. Dynamic rainfall analysis (hyetograph generation).
4. IDF curve generation.
5. Peak flow calculation using the Rational method.
6. Peak flow calculation using Log Pearson Type III analysis.

Example One: Rainfall Intensity & Duration

Problem:

Find the intensity and duration of a 50-yr storm using the kinematic wave method and the following data: overland runoff length equals 61 m, overland runoff slope equals 2 percent, basin Manning's coefficient equals 0.10, channel length equals 655 m, and channel slope equals 1 percent. Latitude equals 41 degrees 31 minutes and longitude equals 124 degrees 2 minutes.

Input File: HYDRO1.HDO

```
JOB Example One: Rainfall Intensity and Duration
RFL 1
TCO 61    0.02    0.1
TCC 655   0.01
LOC 41    31      124      2
RPD 50
END
```

Discussion of output:

The kinematic wave method is performed because only three parameters appear in the **TCO** command. Notice that we do not need the **BAS** command for the kinematic wave approach.

Output File: HYDRO1.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *               Date of Run: 10-15-97             *
                                                                      Page No  1
                   Example One: Rainfall Intensity and Duration

--- Input File: \hydro\hydro1.hdo


 RFL  1

 === RAINFALL ANALYSIS (Intensity Suboption) Selected ...

 TCO  61    0.02    0.1
```

```
*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC  655   0.01

*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 LOC  41    31      124      2

--- The Latitude is 41 degrees, 31 minutes.
--- The Longitude is 124 degrees,  2 minutes.

 RPD  50

--- The Selected Return Period is   50 years.


*** End of Command File

--- Overland Time of Concentration:    .18 h
--- Channel Time of Concentration:     .40 h

                ************************************************
                *  Time of Concentration equals     .58 h      *
                *        Intensity equals       49. mm/h       *
                ************************************************


 +++ NORMAL END OF HYDRO
```

Example Two: Rainfall Intensity - State Data Base

Problem:

Find the intensity and duration of a 50-yr storm using the kinematic wave and the same data from example 1. Use the California State data base.

Input File: HYDRO2.HDO

```
JOB Example Two: Rainfall Intensity and Duration - State Database
RFL    1
TCO   61    0.02     0.1
TCC  655    0.01
LOC   41      31     124       2
RPD   50
CAL RAIN.ASC
END
```

Discussion of output:

The presence of the **CAL** command triggers the California State data base. The final answer is slightly different than example 1.

Output File: HYDRO2.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *              Date of Run: 10-15-97              *
                                                                     Page No  1
           Example Two: Rainfall Intensity and Duration - State Database

--- Input File: \hydro\hydro2.hdo


 RFL     1

 === RAINFALL ANALYSIS (Intensity Suboption) Selected ...

 TCO    61    0.02     0.1

*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC   655    0.01

*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 LOC    41      31     124       2
```

```
--- The Latitude is 41 degrees, 31 minutes.
--- The Longitude is 124 degrees,  2 minutes.

 RPD    50

--- The Selected Return Period is   50 years.

 CAL  RAIN.ASC

 === File Read from Intermediate Directory: RAIN.ASC


*** End of Command File


--- The Following Station(s) Will Be Used in Determining the Sites Intensity:
    Station ID   Elev. (m)   Lat/Long (dec. deg.)  Distance from Site (km)

    F304577000      7          41.517  124.033                .000

    Notice:  A Station Elevation of -999 Indicates A Missing Value.


--- Overland Time of Concentration:    .21 h
--- Channel Time of Concentration:     .40 h

                *************************************************
                *  Time of Concentration equals     .61 h       *
                *        Intensity equals       42. mm/h        *
                *************************************************


 +++ NORMAL END OF HYDRO
```

Example Three: Rainfall Hyetograph

Problem:

Find the intensity, duration, and time to peak of a 50-yr storm using the kinematic wave method and the same data from example 1.

Input File: HYDRO3.HDO

```
JOB Example Three: Rainfall Hyetograph
RFL    2
TCO   61    0.02     0.1
TCC  655    0.01
LOC   41      31     124       2
RPD   50
END
```

Discussion of output:

Notice that the 50-yr hyetograph is plotted and tabulated.

Output File: HYDRO3.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *              Date of Run: 10-15-97              *
                                                                    Page No  1
                        Example Three: Rainfall Hyetograph

--- Input File: \hydro\hydro3.hdo


 RFL     2

 === RAINFALL ANALYSIS (Hyetograph Suboption) Selected ...

 TCO    61    0.02     0.1

*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC   655    0.01

*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 LOC    41      31     124       2

--- The Latitude is 41 degrees, 31 minutes.
--- The Longitude is 124 degrees,  2 minutes.
```

```
 RPD    50

--- The Selected Return Period is   50 years.


*** End of Command File


--- Overland Time of Concentration:    .18 h
--- Channel Time of Concentration:     .40 h

                ************************************************
                *  Time of Concentration equals     .58 h       *
                *        Intensity equals       49. mm/h        *
                ************************************************


--- Internally supplied A-Prime value equals  .431


                   ******************************************
                   *   The time to peak equals   .25 h       *
                   ******************************************
```

***** HYDRO ***** (Version 6.1) *****   Date 10-15-97
Page No 2

Example Three: Rainfall Hyetograph

Graph of Triangular Hyetograph
Rainfall Intensity (mm/h) versus Time (h)

```
99..............................*......................................
   .                          *   *                                   .
   .                                *                                 .
   .                        *         *                               .
74..                      *             *                             .
   .                    *                 *                           .
   .                  *                    *                          .
   .                                         *                        .
   .                *                          *                      .
49..              *                              *                    .
   .            *                                  *                  .
   .           *                                     *                .
   .                                                   * *            .
   .         *                                                        .
25..       *                                                          .
   .     *                                                            .
   .   *                                                              .
   .                                                                  .
   . *                                                                .
 0.*..................................................................*
   .00              .14              .29              .43            .58
```

***** HYDRO ***** (Version 6.1) *****   Date 10-15-97
Page No 3

Example Three: Rainfall Hyetograph

Point	Time (h)	Intensity (mm/h)
1	.000	0.
2	.017	7.
3	.033	13.
4	.050	20.
5	.067	26.
6	.083	33.
7	.100	40.
8	.117	46.
9	.133	53.
10	.150	59.
11	.167	66.
12	.183	73.
13	.200	79.
14	.217	86.
15	.233	92.
16	.250	99.
17	.250	99.
18	.267	94.
19	.283	89.
20	.300	84.
21	.317	79.
22	.333	74.
23	.350	69.
24	.367	64.
25	.383	59.
26	.400	54.
27	.417	49.
28	.433	44.
29	.450	39.
30	.467	34.
31	.580	0.

+++ Notice: Intermediate file has SI units.

=== File Created on Intermediate Directory: hydro3.HYE

+++ NORMAL END OF HYDRO

Intermediate File: HYDRO3.HYE

```
 HYDRO HYETOGRAPH (SI) OUTPUT
   31
         .0         0.
        1.0         7.
        2.0        13.
        3.0        20.
        4.0        26.
        5.0        33.
        6.0        40.
        7.0        46.
        8.0        53.
        9.0        59.
       10.0        66.
       11.0        73.
       12.0        79.
       13.0        86.
       14.0        92.
       15.0        99.
       15.0        99.
       16.0        94.
       17.0        89.
       18.0        84.
       19.0        79.
       20.0        74.
       21.0        69.
       22.0        64.
       23.0        59.
       24.0        54.
       25.0        49.
       26.0        44.
       27.0        39.
       28.0        34.
       34.8         0.
```

Example Four: IDF Curve Generation

Problem:

Find the IDF curve for a 50-yr storm at the following location:

Latitude = 41 degrees 48 minutes
Longitude = 123 degrees 22 minutes

Input File: HYDRO4.HDO

```
JOB Example Four:  I-D-F Curve Generation
IDF Happy Camp Ranger Station
LOC   41     48     123     22
RPD   50
END
```

Discussion of output:

Notice that the 50-yr IDF curve is plotted and other intensities are tabulated for common frequencies.

Output File: HYDRO4.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *              Date of Run: 10-15-97              *
                                                                     Page No  1
                       Example Four:  I-D-F Curve Generation

--- Input File: \hydro\hydro4.hdo


 IDF  Happy Camp Ranger Station

 === IDF CURVE Option Selected ...

 LOC    41      48     123      22

--- The Latitude is 41 degrees, 48 minutes.
--- The Longitude is 123 degrees, 22 minutes.

 RPD    50

--- The Selected Return Period is   50 years.


*** End of Command File
```

***** HYDRO ***** (Version 6.1) *****   Date 10-15-97
Page No 2

Example Four: I-D-F Curve Generation

IDF Curve for Various Return Periods

Intensities (mm/h)

Duration	50 Yr	2 Yr	5 Yr	10 Yr	25 Yr	100 Yr
5 min	114.	78.	89.	97.	107.	121.
10 min	88.	57.	66.	73.	81.	94.
15 min	70.	43.	51.	56.	64.	75.
30 min	47.	27.	33.	37.	42.	51.
60 min	29.	16.	20.	22.	26.	32.
120 min	22.	12.	15.	17.	20.	24.
4 h	17.	9.	11.	13.	15.	18.
8 h	13.	7.	9.	10.	11.	14.
16 h	10.	6.	7.	8.	9.	11.
24 h	8.	5.	6.	6.	7.	9.

Happy Camp Ranger Station
Intensity Curve for   50 Year Return Period
Rainfall Intensity (mm/h) versus Duration (h)

```
114.*...................................................................
    .                                                                  .
    .                                                                  .
    .                                                                  .
 86.*                                                                  .
    .                                                                  .
    .                                                                  .
    .*                                                                 .
    .                                                                  .
 57..                                                                  .
    .                                                                  .
    .*                                                                 .
    .                                                                  .
    .                                                                  .
 29..  *                                                               .
    .     *                                                            .
    .          *                                                       .
    .                     *                      *                     .
    .                                                                  *
  0.....................................................................
    .00             6.00            12.00            18.00          24.00
```

```
                 ***** HYDRO ***** (Version 6.1) *****           Date 10-15-97
                                                                    Page No  3
                       Example Four:  I-D-F Curve Generation

+++ Notice:  Intermediate file has SI units.

=== File Created on Intermediate Directory: hydro4.IDF

+++ NORMAL END OF HYDRO
```

Intermediate File: HYDRO4.IDF

```
 HYDRO IDF (SI) OUTPUT
   10
       5.0       114.
      10.0        88.
      15.0        70.
      30.0        47.
      60.0        29.
     120.0        22.
     240.0        17.
     480.0        13.
     960.0        10.
    1440.0         8.
```

Example Five: Peak Flow Using the Rational Method

Problem:

Find the peak flow of the subbasin in example 1, moved to latitude = 38 degrees 30 minutes and longitude = 80 degrees 50 minutes. The runoff coefficients are: meadow = 0.2, residential = 0.4, and pavement = 0.95. The land use areas are: meadow = 21.8 ha, residential = 20.4 ha; pavement = 1.5 ha.

Input File: HYDRO5.HDO

```
JOB Example Five: Rational Method Peak FLow
FLW    1
RTL    *       *       *       *       *       *    0.95
BAS 21.8       0       0       0    20.4       0     1.5
TCO 61      0.02       0.1
TCC 655     0.01
LOC 38      30      80      50
RPD 50
END
```

Discussion of output:

Notice that results include time of concentration, peak rainfall intensity, and peak flow.

Output File: HYDRO5.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *               Date of Run: 10-15-97              *
                                                                    Page No  1
                      Example Five: Rational Method Peak FLow

--- Input File: \hydro\hydro5.hdo

 FLW     1

 === FLOW ANALYSIS (Rational Method Suboption) Selected ...

 RTL     *       *       *       *       *       *    0.95

 BAS  21.8       0       0       0    20.4       0     1.5

--- The Basin Area is      43.7 ha

 TCO  61      0.02       0.1

*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC  655     0.01
```

```
*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 LOC  38      30      80      50

--- The Latitude is 38 degrees, 30 minutes.
--- The Longitude is  80 degrees, 50 minutes.

 RPD  50

--- The Selected Return Period is   50 years.

*** End of Command File

          Subarea Drainage Area (ha) & Runoff Coefficients

                     Meadow ..........    21.8 C =  .200*
                     Woods ...........      .0 C =  .200*
                     Pasture .........      .0 C =  .300*
                     Crops ...........      .0 C =  .300*
                     Residential .....    20.4 C =  .400*
                     Urban/Highway ...      .0 C =  .700*
                     Pavement ........     1.5 C =  .950
                     - TOTAL Basin Area     43.7 ha -
                     Weighted runoff coefficient is .319

                     Notice: * indicates that a default
                               runoff coefficient used.

--- Overland Time of Concentration:    .15 h
--- Channel Time of Concentration:     .40 h

                ************************************************
                *  Time of Concentration equals     .55 h       *
                *        Intensity equals       90. mm/h       *
                ************************************************


                 ***** HYDRO ***** (Version 6.1) *****           Date 10-15-97
                                                                    Page No  2
                      Example Five: Rational Method Peak FLow

                     ************************************
                     * The Peak Flow is      3.447 m^3/s *
                     ************************************


 +++ NORMAL END OF HYDRO
```

Example Six: Peak Flow Using Log Pearson Type III

Problem:

Find the 500-yr flow at the same gauging station that recorded annual peak flows found in MEDINA.FLW. Use a skew coefficient of 0.236. Because the 500-yr flow is at the same gauging station, we do not need areas. Notice that the FLW command is set to 2.

Input File: HYDRO6.HDO

```
JOB Example Six:  Log Pearson Analysis for the Medina River
FLW 2
LPA 0.236     1
GFL MEDINA.FLW
RPD 500
END
```

Input Data File: MEDINA.FLW

(Note: This is an external file that is placed in the HYDRAIN intermediate directory. The user could have just as easily placed the flow data in LPA.HDO, following the GFL command. Appendix D has further information on this and other command input formats and syntax.)

```
Annual Discharge - Medina River @ San Antonio, Texas: 1940-1982
   43
    71.925
   195.103
   495.545
   342.634
    56.334
   100.242
   900.476
    41.626
    58.050
   492.713
   160.273
    60.881
    22.682
   140.451
    24.494
    33.980
    49.554
   146.681
   261.081
    94.861
    90.614
    86.366
   112.135
    25.202
    60.598
   153.760
    61.164
   155.176
   370.951
    77.305
    95.145
    83.535
```

```
180.095
903.307
274.107
116.949
212.660
130.824
267.311
134.505
 56.067
410.594
231.065
```

Discussion of Output:

Because the 500-yr flow is at the same gauging station, we do not need basin areas. Notice that the **FLW** command is set to 2.

Output File: HYDRO6.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *               Date of Run: 10-15-97             *
                                                                    Page No  1
              Example Six:  Log Pearson Analysis for the Medina River

--- Input File: \hydro\hydro6.hdo

 FLW  2

 === FLOW ANALYSIS (Log Pearson Type III Suboption) Selected ...

 LPA  0.236     1

--- The User-Supplied skew coefficient is  .236
 GFL  MEDINA.FLW

 === File Read from Intermediate Directory: MEDINA.FLW

 +++ Notice:  Intermediate file has SI units.

--- The Following Gage Flows were Entered:
   71.925  195.103  495.545  342.634   56.334  100.242  900.476   41.626
   58.050  492.713  160.273   60.881   22.682  140.451   24.494   33.980
   49.554  146.681  261.081   94.861   90.614   86.366  112.135   25.202
   60.598  153.760   61.164  155.176  370.951   77.305   95.145   83.535
  180.095  903.307  274.107  116.949  212.660  130.824  267.311  134.505
   56.067  410.594  231.065

 RPD  500

--- The Selected Return Period is  500 years.

*** End of Command File

--- Statistical Calculations:
    Mean of the Log Flow Values    2.091
    Computed Standard Deviation     .394
    Computed Skew Coefficient       .236
```

```
--- User-Supplied Skew Coefficient of    .23600
    used in place of the computed coefficient.

             **********************************************
             *  The  500 Year Flow Equals  2190.341 m^3/s *
             **********************************************

                  ------------------------------------
                  Peak Flows for Common Return Periods
                  ------------------------------------
                    Return Period          Peak Flow
                       (Years)              (m^3/s)
                    -------------          ----------
              Selected    500               2190.341
                            2                119.035
                            5                261.526
                           10                402.843
                           25                648.684
                           50                890.813
                          100               1191.815
                  ------------------------------------
```

```
                ***** HYDRO ***** (Version 6.1) *****           Date 10-15-97
                                                                   Page No  2
             Example Six:  Log Pearson Analysis for the Medina River
                           Exceedence Probability
     (99.865)  (97.73)   (84.13)   (50.00)   (15.87)   (2.27)    (0.135)
    3.24+.........|.........|.........|.........|.........|.........+
        .         |         |         |         |         |        o.
        .  x - ACTUAL DATA  |         |         |         |         .
F       .  o - CALCULATED   |         |         |         |  o      .
L    .89+  * - BOTH         |         |         |         |*        +
O       .         |         |         |         |       o |         .
W       .         |         |         |         |  x x    |         .
        .         |         |         |         |xxo      |         .
1    .25+         |         |         |      x*x|         |         +
0       .         |         |         |  x xx   |         |         .
0       .         |         |         *xxx      |         |         .
0       .         |         |     xxxx|         |         |         .
     .07+         |         | x xx    |         |         |         +
C       .         |         xxx       |         |         |         .
M       .         |    x  x |         |         |         |         .
S       .         |xx       |         |         |         |         .
     .02+.........x.........|.........|.......|.|..|....|.||.|.....|+
                                      2       5   10   25 50 100  500
      (3.0)     (2.0)     (1.0)     (0.0)    (-1.0)    (-2.0)    (-3.0)
                    Return Period in Years, (Stand. Dev.)

+++ Notice:  Intermediate file has SI units.

=== File Created on Intermediate Directory: hydro6.Q

+++ NORMAL END OF HYDRO
```

Intermediate File: HYDRO6.Q

```
LOG PEARSON III (SI) OUTPUT
   7
       2.   119.035
       5.   261.526
      10.   402.843
      25.   648.684
      50.   890.813
     100.  1191.815
     500.  2190.341
```

APPENDIX B: FOOTPRINTS FOR TYPICAL APPLICATIONS

This section presents four basic HYDRO applications represented by an arrangement of command strings. These arrangements of command strings, or footprints, are provided for the following typical applications:

1. IDF curve.

2. Rainfall analysis (peak rainfall intensity).

3.* Flow analysis (Rational method).

4.* Flow analysis (Log Pearson Type III method).

* Note: This application has the option to generate a hydrograph from its peak flow.

These four footprints are contained in files on the HYDRAIN package diskettes. These files contain the footprint command lines with blank data fields for which the user can supply the appropriate data (the footprint files should be copied and renamed before any editing is done).

1. IDF Curve

Filename: IDF˜FP.HDO

The following command string is a typical footprint for an Intensity-Duration-Frequency (IDF) curve:

```
rem--->Intensity-Duration-Frequency (IDF) curve
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
IDF
rem--->OPTIONAL---UIT command
UIT
rem--->LOC command NOT necessary with UIT command
LOC
RPD
END
```

2. Rainfall Analysis

Filename: RAIN˜FP.HDO

The following command string is a typical rainfall analysis footprint for peak rainfall intensity:

```
rem--->Peak Rainfall Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
RFL 1
rem--->BAS command required only if SCS curve number is used.
BAS
rem--->USE: <TCO and TCC> or <TCU>
TCO
TCC
TCU
LOC
RPD
END
```

3. Flow Analysis - Rational Method

Filename: RATL˜FP.HDO

The following command string is a typical flow analysis footprint for the Rational method:

```
rem--->Rational Method Flow Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
FLW 1
rem--->RTL command required for Rational method
RTL
BAS
rem--->USE:  <TCO and TCC> OR <TCU> OR <TCU and UIT>
TCO
TCC
TCU
UIT
rem--->LOC command NOT necessary when both <TCU and UIT> are used
LOC
RPD
rem--->OPTIONAL---DHY and TLG commands are needed for a HYDROGRAPH
DHY
TLG
rem--->OPTIONAL---MOF command (requires LOC and BAS commands)
MOF
END
```

4. Flow Analysis - Log Pearson Type III Method

Filename: LPIII˜FP.HDO

The following command string is a typical flow analysis footprint for the Log Pearson Type III method:

```
rem--->Log Pearson Type III Flow Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
FLW 2
GFL
RPD
rem--->OPTIONAL---LPA and QAA commands contain Log Pearson III parameters
LPA
QAA
rem--->OPTIONAL---DHY and TLG commands are needed for a HYDROGRAPH
DHY
TLG
rem--->OPTIONAL---Maximum Observable Flood:  MOF and LOC commands
MOF
LOC
END
```

APPENDIX C: HYDRO COMMANDS

This appendix details the meaning and syntax of each command available in HYDRO. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. Any important notes pertaining to the command are also included.

COMMAND AHY- semi-Arid HYdrograph

Purpose: To signal HYDRO to calculate a semi-arid hydrograph.

Structure:

AHY (aarea)

aarea - area of watershed, ha.

Notes:

1) If not already supplied to input file by the BAS or QAA commands.

2) The RPD and FLW commands must also appear in the input file when using AHY.

COMMAND APM - user-supplied APriMe value

Purpose: To specify a user-supplied regional A prime value. This optional command is used when the user wants to create a hyetograph.

Structure:

APM aprm

aprm - OPTIONAL - user-supplied A prime value. The A prime value is used in conjunction with the Yen and Chow synthetic triangular hyetograph method. The value of A prime is the ratio of the time to peak rainfall to the entire rainfall duration. A prime varies based on the geographical location of the user. If the user does not employ this command, HYDRO will determine a default value of A prime using an internal data base that is based on latitude and longitude.

Note: Use of the command APM is only allowed when the RFL switch is set equal to 2.

COMMAND BAS - subBASin area information

Purpose: To specify subbasin sizes.

Structure:

BAS a_mdw, a_wds, a_pas, a_crps, a_res, a_urb, a_pav

1)	a_mdw -	area of land use that contains a meadow or open field, ha .
2)	a_wds -	area of land use that contains forests or woods, ha.
3)	a_pas -	area of land use that contains pasture, ha.
4)	a_crps -	area of land use that is composed of crops, ha.
5)	a_res -	area of land use that contains residential development, ha.
6)	a_urb -	area of land use that contains urban sections or highway right-of-way, ha.
7)	a_pav -	area of land use that contains pavement, ha.

Notes:

1) The basin area is broken into 7 different land use subareas–Meadow, Woods, Pasture, Crops, Residential, Urban/Highway Right-of-way, and Pavement.

2) The total of the subareas will be used as the total basin area.

3) The total basin area will be displayed.

4) Depending on the overland time of concentration method used, various basin area limitations may be observed. The equations in the SCS Curve Number method are designed for basin areas of 800 ha or less. For the Kinematic Wave method, there are no basin area constraints, although for both the Kinematic and Curve Number methods, care should be exercised when using the Rational method. HEC-12 suggests that a practical area limitation may be less than 120 ha.

COMMAND CAL - CALifornia (or state) rainfall data base

Purpose: To specify the filename of the State rainfall data base if the NWS data base is not to be used.

Structure:

CAL filename

filename - a string of not more than 12 characters which represents the name of the file containing the State rainfall data. (The format of this file is described in appendix D of the HYDRO documentation.)

Notes:

1) The CAL command allows the user to access a data base developed specifically for a particular State. Use of such a localized data base is particularly appropriate for western States where rainfall patterns can vary greatly over short distances. (For several of the western States, the RAIN.PFP data base has proven to be too coarse for accurate application.)

2) The format of the State data base is that used by the California Department of Transportation. The logic used to calculate intensity is modeled after the CALTRANS IDF program.

COMMAND CRP - California (or state) Return Period information

Purpose: To specify the necessary data for redefining State rainfall data base statistical information.

Structure:

CRP dmean, pfact, cv

1)	dmean	-	mean 1-h storm, mm/25.4.
2)	pfact	-	Log-Pearson frequency factor.
3)	cv	-	coefficient of variation.

Note: The CAL command must be present if the CRP command is used.

COMMAND DHY - Dimensionless HYdrograph

Purpose: To signal the computation of a hydrograph from the Nationwide Urban (default) or user-supplied dimensionless hydrograph coordinates.

Structure: (three options)

DHY (no parameters)

-- OR --

DHY dhydtd(1), dhydqd(1), dhydtd(2), dhydqd(2), ...dhydtd(n), dhydqd(n)

-- OR --

DHY filename

1)	dhydtd -	user-supplied abscissa value.
2)	dhydqd -	user-supplied ordinate value.

filename - a string of not more than 12 characters representing the name of the file containing the dimensionless hydrograph coordinates. Up to 150 pairs of abscissa and ordinate values may be supplied by the user. The format of the file is described in appendix D of the HYDRO documentation.

Notes:

1) If no fields are specified, then the Nationwide Urban dimensionless hydrograph coordinates will be used in computing the hydrograph.

2) The TLG command must be present in a command string containing the DHY command.

COMMAND END - END of run

Purpose: To signal the end of the command string.

Structure:

END (no parameters)

Note: An END command must be present and must be the last card in a command string.

COMMAND FLW - FLoW analysis method switch

Purpose: To specify the method for determining peak flow.

Structure:

FLW method

method - number indicating the method to be used in computing peak flow. These are:

1 - Rational method. Command RTL should be used to specify the runoff coefficients unless default values are desired.

2 - USGS method (Log Pearson Type III). The GFL and LPA commands should be used to specify gage flows and LPIII constants.

3 - Regression. The RGR command should be used to specify the regression coefficients.

4 - User-supplied method. This option requires use of the QPK command to supply peak flow information.

Notes:

1) The FLW command is one of the three “branch” commands. The branch commands determine what general type of computations are to be made. Only one branch command can be used in a command string and the branch command selected must be the second non-REM command in the string.

2) There are three design flow options. These are: Rational Method, Log Pearson Type III analysis, and User-Developed Regression Equations. These options can produce input to other PFP programs.

The first option uses the Rational method equation (Q = CiA) to calculate the peak flow (in cubic meters per second) at a site. The rainfall intensity is calculated for a specific return period and duration (time of concentration) using the default rainfall data base (RAIN.PFP), the State's data base, or a value supplied by the user on a TCU command. The area variable is developed using seven land use subareas (specified on the BAS command). Default runoff coefficients are provided (or can be replaced at the user's option) with the RTL command. A hydrograph can be developed from dimensionless hydrograph coordinates and data provided with the DHY and TLG commands.

The second option uses Log Pearson Type III analysis with USGS gage station data to calculate the peak flow (in cubic meters per second) at a site. The gage station data must be found and input by the user. Several sources of this information are provided in the HYDRAIN System Shell resources help screen. The DHY and TLG commands can be used to develop a hydrograph from dimensionless hydrograph information. The Log Pearson Type III analysis is designed for 30 or more records; however, the program has been run successfully with as few as 7 flow records.

If option 3 is selected, a user-developed regression equation can be specified using the RGR command. This option allows users to develop their own site specific and general peak flow equations (or use USGS 3 and 7 Parameter Regression Peak Flow Equations). The user supplies the coefficients and exponents to develop an equation of the general form:

Y = ACOF * X(1)**B(1) * ... * X(NCOF)**B(NCOF) .

3) Methods 1, 2 and 3 generate peak flows for hydrographs. The user supplies the peak flow for method 4. To activate the hydrograph computations:

a) The DHY command invokes the USGS urban hydrograph.
b) The AHY command invokes the semi-arid hydrograph.

COMMAND GFL - Gage FLow

Purpose: To specify gage flows for Log Pearson Type III analysis.

Structure: (2 options)

GFL q(1), q(2), ..., q(nyr)

-- OR --

GFL filename

OPTION 1:

q - gage flow for a particular water year, m^3/s.

OPTION 2:

filename- a string of not more than 12 characters representing the name of the file containing the gage flows. Up to 150 flows can be specified by the user. The format for the file is described in appendix D of the HYDRO documentation.

Notes:

1) The flow data are the annual peak flow readings taken at the gage site. Generally, it is recommended that at least 30 years of flow records be obtained for the Log Pearson Type III analysis to describe the probabilistic nature of streamflow. Contact a local USGS office or NAWDEX for more information.

2) The FLW method switch must be equal to 2.

COMMAND IDF - Intensity-Duration-Frequency curve

Purpose: To signal computation and plotting of an IDF curve.

Structure:

IDF graphtitle

graphtitle- alphanumeric characters (up to 73) to be used as the plot label. Commands LOC and RPD must accompany the IDF command.

Notes:

1) The IDF command is one of the three "branch" commands. The branch commands determine what general type of computations are to be made. Only one branch command can be used in a command string and the branch command selected must be the second non-REM command in the string.

2) This command signals computation and plotting of an intensity duration frequency (IDF) curve for a desired site and return period. The desired site is specified using the LOC command and the desired return period is specified with the RPD command. The default rainfall data base RAIN.PFP will be accessed unless the CAL command is used to indicate that the State's data base is to be used. If the default data base is used, the site must be within the continental United States.

3) The duration ranges from 5 min up to 24 h. The return period can range from 2 to 100 years. A plotting routine puts these IDF ordinates on a graph where the y-axis is intensity in inches per hour, and the x-axis is duration in hours. Two graphs are created: one plots all points for durations up to 24 h; the second details the first 2 h of the first curve.

COMMAND JOB - JOB start

Purpose: To initiate job and specify a job title.

Structure:

JOB jobtitle

jobtitle- alphanumeric characters (up to 73) describing the job.

Note: JOB must be the first command. Only one JOB command per command string is permitted. The information in jobtitle becomes a header for the output file.

COMMAND LOC - LOCation of site

Purpose: To specify the latitude and longitude for use in computations requiring data base retrievals.

Structure:

LOC d_lat, m_lat, d_lng, m_lng

1) d_lat - degrees latitude of the site.
2) m_lat - minutes latitude of the site.
3) d_lng - degrees longitude of the site.
4) m_lng - minutes longitude of the site.

Notes:

1) If the RAIN.PFP data base is to be accessed, then the site location must be within the continental United States. If the State data base is to be accessed, then the location must be within the boundaries of that data base.

2) The LOC command must be present when using the MOF command.

COMMAND LPA - Log Pearson type III Analysis

Purpose: To specify constants for Log Pearson Type III analysis.

Structure:

LPA skw, pflag

1) skw - skew coefficient. If an asterisk (*) is specified for skw, then HYDRO will compute a skew coefficient.
2) pflag - flag that signals whether probability curve is to be displayed:
   - 0 - probability curve not displayed. (default).
   - 1 - probability curve sent to output file.
   - 2 - probability curve displayed on the screen.
   - 3 - probability curve sent to output file and displayed on the screen.

Note: To use the LPA command, the FLW method switch must be equal to 2.

COMMAND MOF - Maximum Observable Flood

Purpose: To signal computation of the maximum observable flood.

Structure:

MOF (abas)

abas - area of the basin, ha.

Note:

1) The parameter is not required if area supplied by some other command.

2) The LOC command must also appear in the command string when MOF is used.

COMMAND QAA - Flow Area Adjustment

Purpose: To specify adjustment parameters for Log Pearson Type III analysis.

Structure:

QAA abas ast aexp uni

1) abas - area of the basin, ha, ac, or mi^2.
2) ast - gauging station area, ha, ac, or mi^2a. The station area is the drainage area associated with the flow measured by a USGS (or other) stream gage. Each gage has an associated station, which can be located by the USGS gage number. The station area is measured in ha with limitation 405,000 ha on the total area.
3) aexp - area fraction coefficient having a value greater than or equal to 0 with a default value of 1.0. It is used in the following manner:

$$Q_{BASIN} = Q_{STATION} \times (A_{BASIN}/A_{STATION})^{aexp}$$

4) uni - units flag:
   - 0 or * - area of abas and ast, ac.
   - 1 - area of abas and ast, mi^2.
   - 2 - area of abas and ast, ha (default).

Notes:

1) To use the QAA command, the FLW method switch must be equal to 2.

2) The default units for abas and ast are ac but may be changed using the uni parameter.

3) The station location should possess the following characteristics:
   - Station location is close to the desired point of study.
   - Station has a consistent and long record of flow data available. This will increase the accuracy of the probability analysis and output. The Water Resources Council recommends that there be at least 30 years of annual data available. HYDRO has run on as few as 7 years of data.
   - Station is not affected by inflow of water systems other than the one chosen for the study.
   - Station area characteristics are similar to area of study.

4) If abas is equal to ast, then the watershed is assumed to be at the same location as the gage. If abas is less than ast, then the watershed is upstream of the gage. If abas is greater than ast, then the watershed is downstream of the gage.

COMMAND QPK - User-supplied peak flow.

Purpose: To supply a peak flow or override the computed peak flow for use in deriving a hydrograph from a dimensionless hydrograph.

Structure:

QPK qpu

qpu - user-supplied peak flow, m^3/s.

Note: The QPK command can be used with any of the four FLW options. If the command is used with options 1, 2, or 3, the user-supplied peak flow will override that computed by HYDRO for use in deriving the hydrograph. If used with option 4, the command supplies the peak flow value needed for deriving the hydrograph.

COMMAND REM - REMark

Purpose: To provide remarks or comments.

Structure:

REM (any alphanumeric characters)

COMMAND RFL - RainFalL computation switch

Purpose: To specify whether a single rainfall intensity or a hyetograph is to be computed.

Structure:

RFL option

option - number indicating whether intensity or a hyetograph is to be computed:
1 - compute rainfall intensity.
2 - compute a Yen & Chow hyetograph.

Notes:

1) The RFL command is one of the three "branch" commands. The branch commands determine what general type of computations are to be made. Only one branch command can be used in a command string and the branch command selected must be the second non-REM command in the string.

2) There are two design rainfall options associated with the RFL command. The first option is used to determine a single rainfall intensity for a desired return period and a duration (assumed to be time of concentration in hours) at a site. The second computes the Yen and Chow triangular hyetograph. Both design rainfall options use an unique rainfall intensity data base (RAIN.PFP) that contains rainfall values for the contiguous United States to perform calculations. The user can, however, choose to access a data base developed for a particular State by means of the CAL command. Both options also allow the user to input their own duration and/or rainfall intensity values by means of the TCU and UIT commands.

COMMAND RGR - ReGRession

Purpose: To specify regression coefficients for peak flow computations. The equation is log-log and takes the form:

Y = ACOF * X(1)**B(1) * ... * X(NCOF)**B(NCOF).

Structure: (2 options)

RGR acof, x(1), b(1), ..., x(ncof), b(ncof)

-- OR --

RGR filename

OPTION 1:

1) acof - intercept.
2) x(j) - value of parameter.
3) b(j) - value of exponent.

OPTION 2:

filename - a string of not more than 12 characters representing the name of the file containing the regression coefficients. Up to 150 pairs of x and b values can be specified. The format of the file is described in appendix D of the HYDRO documentation.

COMMAND RPD - Return PerioD

Purpose: To specify the return period for frequency-dependent calculations.

Structure:

RPD rp

rp - return period, years.

Notes:

1) The return period is a function of the probability of rainfall intensity having a certain value over a given period. The return period is measured in years.

2) The command is required in nearly all command strings, except those which use regression, and can be used anywhere after the second non-REM command. If the default rainfall data base is to be accessed, then the return period should be within the range of 2 to 100 years. (Return periods less than 2 years will be set equal to 2 years; return periods greater than 100 years will be set equal to 100 years.)

COMMAND RTL - RaTionaL method runoff coefficients

Purpose: To specify runoff coefficients for each of seven land use categories.

Structure: (2 options)

RTL (no parameters)

-- OR --

RTL C_mdw, C_wds, C_pas, C_crps, C_res, C_urb, C_pav

1)	C_mdw -	runoff coefficient for meadow. If an asterisk (*) is specified, C_mdw will be assumed to equal 0.2.
2)	C_wds -	runoff coefficient for woods. If an asterisk (*) is specified, C_wds will be assumed to equal 0.2.
3)	C_pas -	runoff coefficient for pasture. If an asterisk (*) is specified, C_pas will be assumed to equal 0.3.
4)	C_crps -	runoff coefficient for crops. If an asterisk (*) is specified, C_crps will be assumed to equal 0.3.
5)	C_res -	runoff coefficient for residential. If an asterisk (*) is specified, C_res will be assumed to equal 0.4.
6)	C_urb -	runoff coefficient for urban/highway right-of-way. If an asterisk (*) is specified, C_urb will be assumed to equal 0.7.
7)	C_pav -	runoff coefficient for pavement. If an asterisk (*) is specified, C_pav will be assumed to equal 0.9.

Notes:

1) Similar to what appeared in HEC-12, the basin area is broken into 7 different land use subareas - Meadow, Woods, Pasture, Crops, Residential, Urban/Highway Right-of-way, and Pavement, each with a corresponding runoff coefficient. Unless otherwise specified, the program will use the default runoff coefficients. Default values are used for any fields for which an asterisk (*) is designated. If the default values for all seven categories are desired, leave all fields blank.

2) This command should appear in all command strings in which the FLW command method is set equal to 1.

COMMAND STN - STatioN identification

Purpose: To retrieve rainfall data for a particular station within a State rainfall data base.

Structure:

STN stnid

stnid - a string of not more than 10 characters which identifies a station within a State data base.

Notes:

1) Only one station can be specified per STN command. Up to four STN commands can be used per command chain. The CAL command must also be present in the input file.

2) Care should be used in selecting the stations which will be used for interpolating the 1-h intensity and log-log slope of the IDF curve. The following points should be kept in consideration:
   - If a station is within 5 km of the site, then the data collected for that station should be used rather than interpolated data.
   - Avoid selecting stations that are located on the opposite side of a ridge from the site.
   - Avoid stations with elevations greatly different from that of the site.

3) If stations are not specified by the user, then HYDRO will attempt to locate four stations within +/- 0.25 degrees of the site. These four stations should be checked in accordance with the three points above.

COMMAND TCC - Time of Concentration for Channel flow

Purpose: To specify data for computing channel time of concentration by one of three methods.

Structure: (3 options)

TCC lchl, schl, smngs, sgtr, tgtr << HEC-12 Gutter Section

-- OR --

TCC lchl, schl, smngs, 0, hydr << Manning's Formula

-- OR --

TCC lchl, schl << SCS Grassy Waterway

OPTION ONE: HEC-12 Gutter Section:

1) lchl - channel length, m.
2) schl - channel slope, m/m. Channel slope refers to the average slope of the channel over its entire length.
3) smngs - Manning's coefficient. If '*' is specified for smngs, the default value of 0.016 will be used.
4) sgtr - gutter cross slope, m/m.
5) tgtr - gutter spread, m. The HEC-12 gutter equation will be used to compute channel velocity.

OPTION TWO: Manning's Formula:

1) lchl - channel length, m.
2) schl - channel slope, m/m. Channel slope refers to the average slope of the channel over its entire length.
3) smngs - Manning's coefficient. If '*' is specified for smngs, the default value of 0.016 will be used.
4) 0 - enter zero as a placeholder.
5) hydr - hydraulic radius, m. Manning's formula will be used to compute channel velocity.

OPTION THREE: SCS Grassy Waterway:

1) lchl - channel length, m.
2) schl - channel slope, m/m. Channel slope refers to the average slope of the channel over its entire length.

Notes:

1) The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. Channel time of concentration can be developed using one of three methods: HEC-12 triangular gutter approach, Manning's formula, or the SCS grassy waterway method.

2) The triangular gutter equation is a special case of the regular Manning's formula. It was developed in HEC-12.[2] The equation describes flow in wide, shallow, triangular channels. The area of the gutter and the hydraulic radius are a function of the spread and the roadway cross slope. The triangular gutter channel alternative requires that data be placed in every field: channel flow length, channel slope, Manning's roughness coefficient, gutter side slope, and gutter spread.

3) The Manning's formula alternative requires the data to be placed in the first two fields, channel flow length and channel slope. Additionally, the roughness coefficient is placed in the third field, the gutter side slope is set equal to 0 in the fourth field, and the hydraulic radius is placed in the fifth field. Proper use of this alternative will require trial and error calculations to determine a proper hydraulic radius.

4) The SCS grassy waterway method is a subset of the Upland Method described in the SCS handbook.[14] It describes a linear relationship between velocity and watershed slope when the variables are placed on a log-log graph. This alternative requires only the first two fields, channel flow length and channel slope.

5) Use only one TCC command per job. If channel has multiple hydraulic characteristics, attempt to develop a composite channel section.

COMMAND TCO - overland time of concentration

Purpose: To specify data for computing overland time of concentration by one of two methods.

Structure: (2 options)

TCO llnd, slnd, isoil, iclm (,cnmbr) << SCS Curve Number

-- OR --

TCO llnd, slnd, rmngs << Kinematic Wave

1) llnd - length of overland flow path, m. Overland length refers to the maximum length (m) of flow to the channel in the basin area. Specifically, it can be thought as the travel path required to convey the most "remote" flow to the channel or basin outlet.

2) slnd - slope of overland flow path, m/m. Overland slope refers to the average slope of the land draining to the channel or basin outlet. For example, an 8-m rise occurring over a 100-m length has a slope of 8/100 (rise/run) or 0.08 m/m.

OPTION ONE: SCS Curve Number

3) isoil - letter indicating hydrologic soil type:

A - lowest runoff potential (sand). Sand is defined as deep sand and loess with aggregated silts. The composition is 90 to 100 percent sand/gravel. There is a high infiltration rate of 8 to 11 mm/h.

B - mod. low runoff potential (sand/loam). Sand/loam is defined as shallow loess/sandy loam with a moderate infiltration rate of 4 to 8 mm/h.

C - mod. high runoff potential (clay/loam). Clay/loam is defined as soil low in organic content and usually high in clay. It has a slow infiltration rate of 1 to 4 mm/h.

D - high runoff potential (clay). Clay is defined as a mixture of heavy plastic clay (90 to 100 percent) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 1 mm/h.

4) iclm - climate type:

- 1 - dry. A dry climate has soil that is dry, but not dry enough to cause plants to wilt. Satisfactory cultivation has taken place. A dry climate has 0 to 635 mm of rain/year.
- 2 - typical. A typical climate receives 635 to 1270 mm of rain/year.
- 3 - wet. A wet climate experiences heavy rainfall and water-saturated soil. Over 1270 mm of rain fall each year.

5) cnmbr - OPTIONAL - SCS curve number. This field allows the user to supply a curve number value, overriding the calculated value. The field can be left blank if isoil and iclm are input as values greater than 0.

OPTION TWO: Kinematic Wave

3) rmngs - Manning's coefficient for the basin. Sample ranges can be from 0.4 to 0.01. The user's best judgment is required to select a reasonable value. Use this parameter for kinematic wave method.

Notes:

1) The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents: overland and channel (or gutter) flow. Overland time of concentration is developed by one of two methods: the SCS curve number or by the kinematic wave approach.

2) The Soil Conservation Service, in Technical Release 55, describes a method for determining the overland time of concentration known as the curve number (CN) method.[14] This method is limited to watersheds less than or equal to 800 ha containing consistent land uses and climatological characteristics.

3) The alternative overland time of concentration method that is found in HYDRO is the kinematic wave approach. It is used as defined in HEC-12 and based on research conducted for the Maryland State Highway Administration and the FHWA.[2][16] The kinematic wave approach recognizes that overland flow can be simulated by a moving film of turbulent flow over the watershed surface. The time of concentration for this wave can be expressed as a function of flow length and slope, Manning's surface roughness factor, and the rainfall intensity.

4) The BAS command is required if using the TCO command with the SCS option. The BAS command is not required if using the kinematic wave option.

5) The TCO command can be used with or without TCC. If TCO is not used, the overland time of concentration will be set equal to 0.

COMMAND TCU - Time of Concentration supplied by User

Purpose: To specify time of concentration.

Structure:

TCU tc

tc - time of concentration, h.

Notes:

1) The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. With the TCU command, the combined time of concentration can be specified by the user.

2) The user-defined time of concentration should represent the total time of concentration (overland + channel). Therefore, the commands TCC and TCO should not appear in the same command string with TCU. If TCU does appear in a string with either TCO or TCC, an error will message will be printed and HYDRO will be terminated.

COMMAND TLG - Time LaG

Purpose: To specify the time lag or the information necessary to compute the time lag so that a hydrograph can be computed from a dimensionless hydrograph.

Structure: (2 options)

TLG tl << User-Supplied Time Lag

-- OR --

TLG bdf, dhsl, dhln << USGS Regression Formula

OPTION ONE: User-supplied Time Lag

tl - user-supplied time lag, h.

OPTION TWO: USGS Regression Formula

1) bdf - basin development factor. The bdf should be a number between 0 and 12, with 0 representing an undeveloped basin and 12 representing a fully developed basin.
2) dhsl - main channel slope, m/m.
3) dhln - main channel length, m.

Notes:

1) The TLG command must be present in a command string containing the DHY command.

2) If used with FLW option 4, this command supplies the time lag method for deriving the hydrograph.

COMMAND UIT - User-supplied rainfall InTensity

Purpose: To specify the intensity of a 1-h storm of any return period.

Structure:

UIT itc

itc - user-supplied intensity, mm/h.

Notes:

1) The UIT command can be used in any command string in which the RFL command is used or in which the FLW switch is set equal to 1 (Rational method).

2) The TCU command must be used in conjunction with the UIT command.

3) HYDRO considers that the rainfall intensity associated with the UIT command has already been adjusted for return period.

4) The program adjusts the intensity from the 1-h duration to an intensity associated with the time of concentration specified in the TCU command.

5) Neither the RPD or LOC command are necessary in a command string that has the UIT command.

APPENDIX D: REQUIRED FORMAT FOR INTERMEDIATE FILES

The format of the external rainfall data file to be read by HYDRO as an alternative to RAIN.PFP is modeled after that currently used by the CALTRANS IDF program developed by the California Department of Transportation.

The rainfall data file must be an ASCII file consisting of not more than 255 records (lines of information). The first record must provide the number of records that follow (i.e., the number of stations in the data file). The following records provide information about the individual stations (one record per station). Required format is as presented below:

Required Format for State Rainfall Data Bases

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	Number of stations in data file	I3
	Record length =	3
SUBSEQUENT RECORDS:	Name of station	A20
	Station elevation (ft)	I4
	Station latitude (dec. deg.)	F6.3
	Station longitude (dec. deg.)	F7.3
	County abbreviation (not read)	A3
	One-hour rainfall intensity for six default return periods	6F4.2
	Slope of IDF curve (log10/log10)	F6.3
	Station ID	A10
	*Blank character (not read)	1X
	*Beginning year of data (not read)	I4
	*Blank character (not read)	1X
	*Ending year of data (not read)	I4
		2X
	Mean areal precipitation	F5.3
	Regional skew coefficient	F4.2
	Regional coefficient of variation	F5.3
	Distribution correction factor	F5.3
	Record length =	111

Required Format for Gage Flow Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of years of flow record (NUM)	I5
RECORDS 3-NUM:	Gage flow (m^3/s)	F10.3

Required Format for Gage Flow Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of years of flow record (NUM)	I10
RECORDS 3-NUM:	Gage flow (ft^3/s)	F10.0

Required Format for Regression Files

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of pairs of parameters and exponents (x and b pairs)	I10
RECORD 3:	Intercept (acof)	F10.3
RECORDS 4-NUM	Parameter and associated exponent (x(j), b(j))	2F10.3

Required Format for Dimensionless Hydrograph Files

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of dimensionless hydrograph coordinates, (dhydtd, dhydqd pairs)	I10
RECORDS 3-NUM:	dhydtd, dhydqd	2F10.3

Required Format for Hydrograph Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hydrograph coordinates, (time, flow pairs)	I5
RECORDS 3-NUM:	count, time, flow	F10.0, F10.1, F10.3

Required Format for Hydrograph Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hydrograph coordinates, (time, flow pairs)	I10
RECORDS 3-NUM:	count, time, flow	F10.0, F10.1, F10.3

Required Format for IDF Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of coordinates, (ret, intnsty pairs)	I5
RECORDS 3-NUM:	ret, intnsty	F10.1, F10.0

Required Format for IDF Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of coordinates, (ret, intnsty pairs)	I10
RECORDS 3-NUM:	ret, intnsty	F10.1, F10.3

Required Format for Hyetograph Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hyetograph coordinates, (time, intnsty pairs)	I5
RECORDS 3-NUM:	time, intnsty	F10.1 F10.0

Required Format for Hyetograph Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hyetograph coordinates, (time, intnsty pairs)	I10
RECORDS 3-NUM:	time, intnsty	F10.1 F10.3

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